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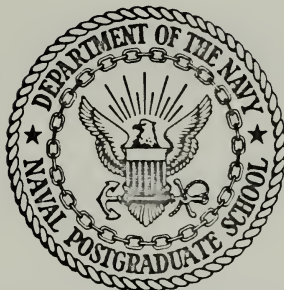
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A LINEAR ECONOMIC MODEL
FOR A NAVAL AIR REWORK FACILITY

William Martin Myers

NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

A Linear Economic Model
for a Naval Air Rework Facility

by

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September 1972

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A Linear Economic Model
for a Naval Air Rework Facility

by

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Submitted in partial fulfillment
of the requirements for the degree of

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ABSTRACT

A prototype management information system called Work-in-Process Inventory Control System (WIPICS) has been installed at the Naval Air Rework Facility (NARF), North Island. WIPICS is expected to benefit the NARF by reducing rework times and rework costs. By assuming that linear production processes may be estimated from statistical data accumulated by the NARF, a linear economic model is constructed which predicts a required budget in man-hours, material cost and overhead cost categories for a specified production output level. Sample problems are solved and parametric studies are done to determine changes in the required budget for restrictions in man-hours, material cost and overhead cost. The model will be used as an aid in the cost-effectiveness evaluation of WIPICS by the Management Systems Development Office.

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I. INTRODUCTION

The Naval Air Rework Facility (NARF) North Island is currently in the process of installing and evaluating a prototype of a recently developed management information system. The system is called the Work-in-Process Inventory Control System (WIPICS) and was designed and developed by the ROHR Corporation, Chula Vista, California. The system employs the latest advances in computer technology which include real time data file updating and information retrieval with communications via a "touch-tone" telephone system and remote teletypewriter terminals. WIPICS contains data regarding individual items and their relationship to the next higher or lower assembly. The system provides an immediate audio (pre-recorded voice) response for simple answers and printed reports for more detailed answers. Each individual item or component has a unique identification number (register number) which is assigned and used for all WIPICS transactions. As an item changes location or status a transaction immediately updates the computer storage record and any subsequent queries will be answered with current information.

The WIPICS formulation concept began in early 1968 when RADM. J. Smith (then NAVAIRSYS COMREPAC) conducted a review of then current management information systems. RADM Smith was convinced that the Uniform Automatic Data Processing

System (UADPS) then being implemented at all Industrial Naval Air Stations (INAS) was rapidly being outdated by the tremendous advances being made in computer technology. Consequently NAVAIRSYSCOM activities were no longer using the most modern management systems available. A "task force" was created and the resulting study was a systems design proposal for the establishment of the Management Systems Development Office (MSDO).

In early 1969 MSDO and the ROHR Corporation studied NARF North Island to determine the applicability of an advanced management information system currently being used by ROHR. The study conclusions led to the development of a contract request for WIPICS by MSDO in late 1969. By July 1970 approval had been granted by SECNAV for MSDO to contract for the construction of a prototype WIPICS to be installed at NARF North Island. The contract negotiation was completed in January 1971. The WIPICS prototype is now installed at NARF North Island and is in an evaluation stage. The expected benefits of WIPICS are three-fold:

- (1) Allow positive control of all work-in-process
- (2) Reduction of turn-around time for repairs
- (3) Improved production rates

Other benefits would be possible if extensions are made to WIPICS:

- (1) Attendance and labor force data
- (2) Association of tooling and technical data

(3) Integrate directly with automated storage areas.

In addition to the approval of a WIPICS prototype in July 1970, SECNAV placed a requirement on MSDO to evaluate the benefits of WIPICS in accordance with the Resources Conservation Program. The documentation for this cost justification was to be developed by MSDO with the methods and data subsequently audited by the Naval Audit Service. Using data collected and summarized by MSDO, the Operations Research/Administrative Sciences Department of the Naval Postgraduate School agreed to conduct a study to develop a methodology for quantitative cost-effectiveness reviews for technological changes of this type.

A brief comparison of the UADPS Feedback system and WIPICS is presented in Figure 1.

B. STATEMENT OF THE PROBLEM

The overall project being considered by the Naval Postgraduate School is the development of a methodology for quantitative cost-effectiveness analysis of technological changes at a particular organization. The results will be specifically applicable to the evaluation of WIPICS at NARF North Island, but may be generalized to any organization which produces several products and incorporates a technological change either in a production process or the control of a production process. The results of this cost-effectiveness analysis will determine the future of WIPICS as a management tool for possible use at other INAS as well as continued use at NARF North Island.

	UADPS Feedback	WIPICS
Data Age/Value	8 to 32 hours from time of occurrence (minimum)(history)	Seconds after occurrence (current)
Data Elements	Comprehensive ID and status for individual and end items	Minimum ID, status for individual and end items and <u>clear inter-relation</u> of items to one another
Data Response	Voluminous printed reports for a general area or program available to limited audience	<u>Specific</u> response available throughout the plant to all need to know
Item Relationship	Difficult to recognize sub-items of a higher or lower assembly or operation	Items are chained to their next higher or lower assembly by register number
Process	Batch sequential - must go from end to end of file on a cyclic basis (minimum daily)	Direct access - go to specific record on file in random order on as needed basis

Figure 1. Comparison of UADPS Feedback and WIPICS

The general approach to the development of a methodology will be to estimate production functions of all major programs at NARF North Island both before and after WIPICS installation. A production function involves determining a specific relationship between a selected output measure and selected input variables. By estimating production functions for entire programs it is possible to avoid the measurement of precise relationships between WIPICS and the NARF North Island shops. Two different types of production functions are to be estimated:

- (1) The Cobb-Douglas Production function
- (2) A Constant Elasticity Substitution Production function.

To formulate continuous production functions of this type requires a substantial amount of raw data aggregation and sophisticated regression analysis techniques. In order to validate the models using the above techniques a third model will be constructed. This model will be based on Linear Programming Techniques and will yield a linear approximation to the production functions.

Once the before and after WIPICS production functions have been estimated, the results will be analyzed to determine the effects of WIPICS. The WIPICS effects on production efficiency will be translated into dollar savings for comparison with WIPICS costs.

C. SCOPE OF THIS THESIS

Linear Programming Techniques will be used to formulate two Linear Economic Models for production at NARF North Island. The two models will be for the engine program and the aircraft program. Both models will be examined in detail by using sample production requirements and conducting parametric studies to determine the sensitivity of the solutions obtained. No attempt will be made to compare these models with the continuous models (which are being derived separately) in this thesis.

II. DATA ANALYSIS AND REDUCTION

A. DATA AVAILABLE

The Naval Air Rework Facility North Island and the Management Systems Development Office provided actual historical data for use in constructing and testing the linear economic model. The data is collected by the NARF for submission of reports to higher authority and for budgetary/accounting purposes. For each engine or aircraft that is reworked by NARF North Island certain statistical information is accumulated:

- | | |
|--------------------------------------|---------|
| (1) Type of engine or aircraft | |
| (2) Identification number | |
| (3) Type of work done | |
| (4) Induction date | |
| (5) Production date | |
| (6) Production load norm (man-hours) | (NORM) |
| (7) Airframe change man-hours | |
| (8) Direct labor hours expended | (DMHR) |
| (9) Direct labor cost | (DLB\$) |
| (10) Direct material cost | (DML\$) |
| (11) Applied overhead cost | (DOH\$) |
| (12) Navy Industrial Fund (NIF) rate | (NIFR) |

The manner in which the above statistics are accumulated and used by NARF North Island are enumerated in Ref. 10.

The MSDO personnel furnished a summary listing of the above statistical information for each engine and aircraft reworked at the NARF for the period February 1970 through July 1971. The basic data consisted of approximately 1500 observations on the engine program and 360 observations on the aircraft program. Each "observation" consists of a complete record of the above statistical data for a completed NARF job. This data is listed for reference purposes in Appendix A of Ref. 11'. In order to keypunch the basic data information it was necessary to assign codes for different types of engines/aircraft and the types of work done. These codes are listed in Tables I and II.

B. SELECTION OF INPUT/OUTPUT VARIABLES

From the basic data it was necessary to select input/output variables to be used for the linear economic model. A single variable consisting of NORM was selected for an output measure.

Input variables were selected to be direct man hours expended (DMHR) direct material cost (DML\$), applied overhead cost (DOH\$) and number of days in shop (NDAY). The number of days in shop was defined to be production date minus induction date. These input variables were selected because they were thought to represent the variable costs of production.

The expected benefits of WIPICS as stated in Chapter I would be expected to cause measurable decreases in the

Table I

Codes Assigned to the Engine Program

<u>Engine Type</u>	<u>Code</u>	<u>Engine Type</u>	<u>Code</u>
T58-GE-1 (A/F)	51	T64-GE-3 (A/F)	63
T58-GE-3 (A/F)	53	T64-GE-6B	65
T58-GE-5 (A/F)	55	T64-GE-6B (PAWN)	66
T56-A-8P	56	T64-GE-7 (A/F)	67
T58-GE-5 (C/G)	57	T64-GE-413	69
J57-P-4A/22	71	T58-GE-8F	81
J57-P-10	72	T58-GE-8B	82
J57-P-20A	73	T58-GE-8B/F	83
J57-P-22	74	T58-GE-8B (C/G)	84
J57-P-420	75	T58-GE-8B (HH2)	85
		T58-GE-8B/F (CONV)	86
J79-GE-8B	91	T58-GE-10	89
J79-GE-8B/C	92		
J79-GE-8B (RDTE)	93	* Abbreviations are defined as follows:	
J79-GE-10	95		
		OVHL	= overhaul
<u>Work Type *</u>	<u>Code</u>	CONV	= conversion
OVHL	01	PAR	= planned aircraft repair
OVHL/CONV	02	SUP	= supply
PAR/REP	03	REP	= repair
SUP/REP	04	SEA	= South East Asia
SUP/REP/CONV	05	CONUS	= Continental United States

Table II

Codes Assigned to the Aircraft Program

<u>Aircraft Type</u>	<u>Code</u>	<u>Aircraft Type</u>	<u>Code</u>
C-2A	10	CH-3B	31
E-2A/B	11	RH-3A	32
		SH-3A	33
F-4J	21	SH-3A/G	34
F-4B	22	SH-3D	35
F-4G/B	23	CH-46A	41
F-8J	25	CH-46D	42
F-8H	26	CH-46F	43
RF-8G	27	UH-46A	44
		UH-46D	45
		CH-53A	48
<u>Work Type**</u>	<u>Code</u>	CH-53D	49
OVHL	1*		
PAR	2*		
PAR/CONV	3*		
PAR/MOD	4*		
PAR/MOD/REP	5*		
PAR/REP	6*		
PAR/SEA	7*		
PAR/CONUS	8*		

* Second digit refers to the cycle number of the aircraft.
(A zero means not applicable.)

** See Table I for Work Type abbreviations.

input variables per unit of output demanded. These decreases can in turn be associated with dollar savings and therefore used as a measure of effectiveness for WIPICS.

As a first step in determining the relationships between the available raw data elements, a computer program was written to compute the correlation coefficients between each pair of variables. The results are shown as Tables III and IV. The computer program is described in Appendix A.

C. CLUSTER ANALYSIS

To formulate a linear economic model it is necessary to define a process. A process consists of a mathematical description of the amount of resources used (i.e. labor, material, etc.) to produce a unit amount of an output measure. The problem is how are the raw data observations used to estimate a process. The most natural way would be to estimate a process as an average amount of resources required to do a specific type of work on a certain engine or aircraft. This procedure may not be desirable because there may be alternate processes available to produce the same output. For example, to overhaul an F-8J it may be possible to use a "normal" amount of man-hours and have a low material cost. An alternate process may exist whereby the same work may be accomplished by spending more money on material and reducing the man-hours required.

In an attempt to identify these alternate methods within the basic data observations a clustering algorithm was

CORRELATION FOR RAW DATA - ENGINES

	NORM	DMHR	DLB\$	DML\$	DOH\$	NIFR	NDAY
NORM	1.00000	0.94832	0.94945	0.67620	0.93864	-0.04526	0.47849
DMHR	0.94832	1.00000	0.99695	0.65128	0.99032	-0.10610	0.54876
DLB\$	0.94945	0.99695	1.00000	0.65169	0.98909	-0.10374	0.54283
DML\$	0.67620	0.65128	0.65169	1.00000	0.65288	0.54323	0.45987
DOH\$	0.93864	0.99032	0.98909	0.65288	1.00000	-0.09700	0.55224
NIFR	-0.04526	-0.10610	-0.10374	0.54323	-0.09700	1.00000	0.04808
NDAY	0.47849	0.54876	0.54283	0.45987	0.55224	0.04808	1.00000

	MEAN	STD DEV
NORM	534.25	367.59
DMHR	534.12	376.91
DLB\$	3230.61	2258.22
DML\$	5764.03	5396.77
DOH\$	4045.30	2911.78
NIFR	2515.00	1021.30
NDAY	33.06	10.61

Table III. Correlation Coefficients for Engine Raw Data

CORRELATION FOR RAW DATA - AIRCRAFT

	NDRM	DMHR	DLB\$	DML\$	DOH\$	NIFR	NDAY
NORM	1.00000	0.97123	0.96585	0.60199	0.95801	-0.32822	0.86055
DMHR	0.97123	1.00000	0.99633	0.62193	0.97562	-0.36636	0.87527
DLB\$	0.96585	0.99633	1.00000	0.61766	0.96923	-0.36199	0.87298
DML\$	0.60199	0.62193	0.61766	1.00000	0.61041	0.38659	0.57975
DOH\$	0.95801	0.97562	0.96923	0.61041	1.00000	-0.32157	0.84932
NIFR	-0.32822	-0.36636	-0.36199	0.38659	-0.32157	1.00000	-0.29888
NDAY	0.86055	0.87527	0.87298	0.57975	0.84932	-0.29888	1.00000

	MEAN	STD DEV
NORM	8357.50	4043.53
DMHR	8558.26	4385.91
DLB\$	52886.70	27281.99
DML\$	21155.59	11208.13
DOH\$	54912.00	27878.43
NIFR	1529.10	132.64
NDAY	83.58	34.39

Table IV. Correlation Coefficients for Aircraft Raw Data

developed based on a method described in Ref. 8. A series of four computer programs are necessary to achieve the final results. These programs and the purpose of each are described in Appendices B through E. The general procedure is to select a group of observations containing several different types of engines (or aircraft) and some different types of work within each engine group. These observations are then analyzed mathematically for similarity of a selected vector of input/output measures. Similarity among observations is defined as those vectors that use input resources in approximately the same fixed proportion for a unit output measure.

Several trial selections were made with both engine and aircraft data. The engine data was observed to cluster groups of the same engine type together with a high degree of consistency. For example if 20 J-79 engines were selected as part of a trial run of 100 observations, a typical result would be for 17 or 18 of the original 20 to be clustered in the same group. However, the trial selection with the aircraft data were not nearly so consistent. The cluster analysis showed the aircraft data had wide variations among the input variables. The clusterings observed were highly irregular and containing a mixture of different aircraft and different work.

Based on the results of the engine cluster analysis a decision was made to form processes consisting of only

similar engines (or similar aircraft) with identical types of work.

D. DATA AGGREGATION

For the engine data the identification number consisted of the job order number used at the NARF. The job order number consists of a series of alphameric codes as specified in Ref. 10. Using these codes the entire engine raw data deck was sorted into job order number. Similar engine/work types were then grouped together within each job order. The resulting raw data deck was then ordered by engine type, job type and calender quarter in which the work was done (in special cases where a very few observations were available the engine/job types were not separated into calender quarters). Each calender quarter then represented a separate "process observation" on the NARF. At this point the data deck showed 47 different engine/work types and 103 processes by which the work could be done. A computer program was used to examine the dominance relationships among all processes with the same engine/work type. This computer program is described in Appendix G. The dominance relationships among processes are very important in a linear program. For example, if process 1 and process 2 produce the same output but process 2 uses more of every required resource than process 1, then process 1 dominates process 2. In a linear program that minimizes costs, process 1 will always be selected as preferred to

process 2. Therefore, if the linear programming model is to have alternate processes that reflect choices to be made then the dominance must be eliminated between all processes with the same output.

The computer program in Appendix G was run with the 103 processes as previously determined based on job order numbers. The dominance relationship between each pair of processes that produced the same output was examined. If no dominance existed then that group of alternate processes was left alone. If dominance existed among any of the processes in the group then a subjective decision was made to combine two of the processes. For example, if there were five processes and dominance existed between three pairs of them, then two processes would be selected to be combined. The decision on which pair to combine was entirely subjective. The group would then have four alternate processes remaining. The dominance computer program would then be run again and the remaining alternate processes would be examined for dominance. This procedure was repeated until all dominance was eliminated within process groups that had the same output. Since the outputs were intended to be measured separately (as opposed to an aggregate output measure) it was not necessary to examine the dominance between processes of different outputs.

In combining individual raw data observations into estimated processes an aggregation computer program was used. This program is listed in Appendix F. The program

estimates the process by calculating an average value for each variable on the raw data cards. The resulting engine raw data was aggregated from 103 processes to 81 processes in order to eliminate all "within" group dominance.

The aircraft data consisted of 365 raw data observations. Each type of aircraft and type of work considered as a separate output meant that 70 outputs were required. This small amount of data then had to be used to estimate not less than 70 distinct processes. A decision was made to estimate only a single process for each output because of the limited data available. In this case there were no alternate processes so it was not necessary to check for dominance. The linear program in this case would not have a choice among processes and therefore the solution becomes trivial. Further discussion of the aircraft data is contained in Chapters IV and V.

The final listings of the estimated processes for the aircraft and engine programs are included as Appendixes H and I respectively.

III. LINEAR ECONOMIC MODELS

A. INTRODUCTION

Linear programming is a mathematical technique for solving constrained optimization problems of a special type. A linear economic model is a specific type of linear program consisting of the maximization (or minimization) of a linear function of n variables subject to m linear inequality constraints. Most unconstrained optimization problems may be solved by the determination of critical points and their nature (maximum, minimum or saddle point) through solution of first and second derivative equations. In the case of a linear function the first derivative is a non-zero constant and all higher order derivatives are zero. The addition of a constraint set to the linear function further complicates the mathematics. However, several mathematical tools have been developed to solve optimization problems where the objective function and the constraints are linear functions. The first explicit use of linear programming techniques occurred in connection with planning activities for the U.S. Air Force in the late 1940's. Linear programs (and their close mathematical relative the input-output models) have become increasingly important to microeconomic theory in recent years.

In the linear economic model being constructed it is necessary to define a process. A linear production process

is an activity by which one or more outputs are produced in fixed proportions by the application of one or more inputs in fixed proportions. The production process as defined is homogeneous of degree one which implies constant returns to scale. For example, if all inputs to a process are doubled then the output will also be doubled. A linear production function is formed from a collection of linear production processes that may be used simultaneously.

The optimal solution to a linear economic model as described above consists of finding the combination of m processes from n available processes such that a linear objective function is maximized (or minimized). Detailed information concerning linear programming and microeconomic theory can be found in Refs. 1 through 5 and in Ref. 9.

B. ASSUMPTIONS

The following assumptions are made in the formulation of a linear economic model:

(1) The estimated processes (reworking of engines and aircraft) are linear functions and therefore these processes exhibit constant returns to scale.

(2) The above linear processes may be estimated by the aggregation of a finite set of observations over some time period.

(3) The NARF is not a profit maximizing organization, therefore the management objective of the NARF will be assumed to be minimization of costs subject to completion of all work demanded by the operational forces of the Navy.

(4) Prices used in the model are constant and may be estimated from the production data furnished by the NARF.

C. FORMULATION OF THE LINEAR ECONOMIC MODEL

To present the model it is necessary to have some precise mathematical notation available. Definitions will be as follows:

m = number of output constraints

n = number of production processes

$(n \geq m)$

R = column vector of available resources = $\begin{bmatrix} R_1 \\ R_2 \\ R_3 \end{bmatrix}$

where

R_1 = resource for direct man-hours expended per man-hour of NORM

R_2 = resource for direct material cost in dollars per man-hour of NORM

R_3 = resource for direct overhead cost in dollars per man-hour of NORM

P = column vector of prices associated with R_1 , R_2 and R_3 respectively = $\begin{bmatrix} p \\ 1.0 \\ 1.0 \end{bmatrix}$

where p = price of labor in dollars per man-hour

Z = column vector of activity levels = $\begin{bmatrix} z_1 \end{bmatrix}$
 $i = 1, \dots, n$

T = technology matrix of observed processes at NARF
 $[(m+3) \times n \text{ matrix}]$ = $\begin{bmatrix} T_1 \\ \hline T_2 \end{bmatrix}$

where

T_1 = units of output (NORM)
(mxn matrix)

$$= \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & \dots & 0 \\ 0 & 1 & 1 & 0 & & \dots & 0 \\ 0 & 0 & 0 & 1 & 0 & \dots & 0 \\ \vdots & & & & & & \vdots \\ 0 & \dots & \dots & \dots & 0 & 1 \end{bmatrix}$$

and

T_2 = resource matrix

$$= [r_{ij}]$$

$$i = 1, 2, 3$$

$$j = 1, \dots, n$$

with r_{ij} = amount of i^{th} resource used per unit
output of j^{th} activity.

Y = column vector of production
output desired in man-hours
of NORM.

$$= [y_i]$$

$$i = 1, \dots, m.$$

T_3 = diagonal matrix of number
of days in shop per unit
of output

$$= \begin{bmatrix} t_1 & & & & & & \\ & \ddots & & & & & \\ & & t_1 & & & & \\ & & & \ddots & & & \\ & & & & t_n & & \\ & & & & & \ddots & \\ & & & & & & t_n \end{bmatrix}$$

C = column vector of penalty
costs

$$= [c_i]$$

$$i = 1, \dots, n$$

where c_i = penalty cost in dollars incurred for each day in
shop associated with the i^{th} process.

Now that a basic mathematical vocabulary exists for the variables, processes and costs, the linear economic model will be presented and discussed:

objective function minimize $P^T T_2 Z + C^T T_3 Z$

constraints

$$\text{subject to: } \begin{bmatrix} -T_1 \\ \hline T_2 \end{bmatrix} \cdot \begin{bmatrix} Z \end{bmatrix} \leq \begin{bmatrix} -Y \\ \hline R \end{bmatrix}$$

The objective function consists of two terms:

$P^T \cdot T_2 \cdot Z$ = actual cost in dollars of resources used for activity level vector Z

$C^T \cdot T_3 \cdot Z$ = penalty cost in dollars for activity level vector Z .

The constraint set may also be separated into two parts for discussion:

$-T_1 \cdot Z \leq -Y$ is a set consisting of the first m rows of the constraints which force the activity level vector Z to choose a set of processes which satisfy the production vector Y .

$T_2 \cdot Z \leq R$ consists of the last 3 rows of the constraint set and ensures that actual resources used do not exceed available resources.

D. SOLUTIONS OF THE MODEL

It is clear that the size of the resource vector R is highly dependent on the production vector Y . In fact these two vectors must be chosen carefully to avoid an infeasible

linear program. The easiest approach to avoiding an infeasible linear program is to make the resource vector R very large, therefore the optimal solution to the model will not be constrained by an active resource constraint. In economic terms this means that the "customer" is willing to pay the NARF as much as necessary to accomplish the work specified by production vector Y . If the NARF is assumed to be efficiently operated, then the costs incurred will be minimized.

In summary, the objective function of the model will be a minimum when the model is not constrained by the resource vector R . In other words, the costs are minimum when the resource constraints are inactive constraints. The value of the objective function represents the total cost incurred to accomplish production vector Y based on past performance data of the NARF.

It should be noted that the linear economic model presented in this chapter is not a production management tool in the sense that the model chooses "processes" by which the NARF should rework aircraft or engines. The model only provides a budget cost plus a penalty cost for a specified amount of work to be done. Some information is available from the model concerning tradeoff values among the three resources. The model can also determine the minimum amount of any single resource required to accomplish the specified work. Some example solutions are presented and discussed in the next chapter.

IV. SAMPLE PROBLEMS

A. INTRODUCTION

Two separate models were constructed using forecasted workload requirements during third quarter, fiscal year 1972. The forecasted requirements for the engine and aircraft programs were obtained from Naval Air Rework Facility Production and Planning Notices dated 17 June 1971 and 26 July 1971 respectively. The forecasted requirements were converted into two separate production vectors (Y's).

Penalty costs were computed for each type of engine and aircraft reworked at NARF North Island using information supplied by MSDO. Aircraft penalty costs were computed by prorating the total cost of the aircraft over its estimated service life. The resulting penalty cost was in units of dollars per day in shop. A similar computation was desired for engine penalty costs. However, an estimated service life for each engine was not available. When engines are reworked by the NARF, engine components are replaced as necessary resulting in a "new" engine. For this reason the service life of all engines was assumed to be ten years. Table V shows the computed penalty costs. For convenience Tables V through XI are located at the end of this chapter.

A constant was also needed for converting direct man hours into a dollar cost. As previously defined in Chapter III, this is the value of p in the vector of prices, P .

A computer program was developed to compute the average labor cost. The computer program is shown in Appendix J. The results were as follows:

	<u>p</u> (in dollars per man-hour)
engines	6.04
aircraft	6.17

B. COMPUTATIONAL PROCEDURES

To solve the engine and aircraft linear programs Mathematical Programming System/360 (MPS/360) was used. This IBM applications program is composed of a very complex set of computational procedures. A subset of these procedures are used to solve linear programs. However, the user must construct a control program that orders a specific sequence of procedures to be executed by the computer. A detailed knowledge of Refs. 6 and 7 is necessary to use MPS/360.

In addition to preparing a control program for MPS/360, the linear program input data must be in a special format described in Chapter 4 of Ref. 7. To assist in preparing data in this format a computer program was prepared. This program takes specified input data and produces a deck of punched cards for MPS/360 in the required format. This program is documented in Appendix K.

C. ENGINE MODEL

1. Input Data

The sample data used for the engine model is listed in Table VI. Each row of the T_1 submatrix of matrix T is associated with a specific type of engine and type of work done on that engine. The production vector Y is associated with each row of the T_1 matrix because Y specifies the required number of man-hours of NORM for the particular type of work. The linear program must then choose the process (columns of matrix T) by which the cost of the work will be a minimum. If only one process is available and production is required then the linear program must select that process.

The total amount of resources available are shown as rows R1, R2 and R3. These values form the resource vector R.

The model was solved for three different, but closely related, objective functions. The values listed in columns OBJ1, OBJ2 and OBJ3 of Table VI are calculated as follows:

$$\text{OBJ1} = P^T \cdot T_2 + C^T \cdot T_3 = \text{total cost per unit output of NORM (total cost = resource cost + penalty cost)}$$

$$\text{OBJ2} = P^T \cdot T_2 = \text{resource cost per unit output of NORM}$$

$$\text{OBJ3} = C^T \cdot T_3 = \text{penalty cost per unit output of NORM}$$

In Table VI $\text{OBJ1} = \text{OBJ2} + \text{OBJ3}$ except in cases where numbers were rounded off by the computer.

Recall from Chapter III that the T_1 matrix consisted of a 1 in only one row of each column of T_1 and all the other elements of that column were zeros. The row in which the 1 belongs is given in Table VI in the T_1 ROW column. The columns in Table VI labeled R_1 , R_2 and R_3 are the three elements of the T_2 matrix described in Chapter III. These three values correspond to the amount of each resource required per unit output of NORM for that particular process. The column labeled T_3 in Table VI is the number of days in shop per unit output of NORM for that particular process. The values for vector C are found in Table V. However, the penalty costs per unit output of NORM may be found directly in the OBJ3 column of Table VI. Recall that $OBJ = C^T \cdot T_3$.

2. Solutions

The solutions to the three linear programs (each with a different objective function) using the engine model data are presented in Tables VII, VIII and IX. The optimal solution for each problem is shown in the first column of each Table. The actual choice of processes selected by MPS/360 is not shown, because as stated in Chapter III, these "processes" do not represent actual physical procedures which are used by the NARF. The processes do give an estimate of the total production cost for a specified production vector. The anticipated change in production costs will be the foundation for the cost justification of WIPICS.

It is necessary to explain the relationship between the optimal solutions presented in Tables VII and VIII. The solutions are nearly identical. This result is not unexpected as can be seen in Table VI. The magnitude of OBJ2 (resource cost) is much larger than OBJ 3 (penalty cost) in every case. By attempting to minimize the total cost of production (resource cost + penalty cost) the linear program arrived at a solution that also happened to minimize resource cost. This is not an uncommon result when one component of an objective function is much larger than another component. One might also observe that the value of the objective function in Table VII is approximately 90% resource cost and 10% penalty cost. This is another reason for the two solutions to be similar.

In Table IX the solution to minimization of penalty cost turns out to be very costly in terms of required resource costs. An increase of nearly \$300,000 in resource cost for a penalty cost reduction of only \$20,000 is the difference between Tables VII and IX. The obvious conclusion is that unless penalty cost is higher than presently calculated, the resource cost will nearly always determine the optimal solution. A discussion of alternate methods of determining penalty cost will be discussed in Chapter V.

3. Sensitivity Analysis

Using procedures described in the MPS/360 references a parametric study was done on the resources DMHR, DML\$ and DOH\$. Since the optimal solution was obtained with

unconstrained resources available it is not necessary to increase any resource. The optimal solution shown in Tables VII, VIII and IX will remain the same for all values of resources greater than those shown in Table VI. It is possible to obtain different solutions to each model by decreasing the resources one at a time until the linear program becomes infeasible. Infeasible means that there is not enough of some resource in R to accomplish the work specified by the production vector Y. In other words, a conflict exists between some of the constraints in the model and no solution exists for that linear program. The results of decreasing each resource (one at a time) are shown in the parametric studies section of each solution table.

If the available quantity of a resource is reduced in value until the entire quantity is consumed in production, then any further reduction below that value will result in an increased cost in the objective function. In linear programming terms the shadow price of the dual variable associated with that resource constraint is frequently positive when the constraint is binding. The increased cost of production as described above can be observed in Tables VII through IX.

An interesting result appears in Tables VII and VIII. When the DMHR resource was reduced, the DOH\$ resource was also reduced in the new solution (but the DML\$ resource use increased). The explanation for this effect is found in Table III. The correlation coefficient between DMHR and

DOH\$ is +.99032. This high correlation suggests that overhead costs at the NARF are applied to each job based on the DMHR for the job. This is the way overhead costs are applied at NARF, North Island. Therefore, a decrease in available DMHR could also cause a reduction in DOH\$ used.

In summary, the parametric studies on the resource vector indicate the minimum amount of available resources required for a feasible linear program. However, if all three resources are reduced to their respective minimum values at the same time an infeasible linear program will result. The reason for this may be seen in Table VII. In reducing DMHR the requirement for DML\$ is increased. The parametric study results as shown were used to constrain only a single resource and the two remaining resources were considered available in unlimited amounts. Other types of parametric studies are available if desired. For example, all three resources may be changed in fixed proportions. The MPS/360 Users Manual (Ref. 7) discusses available post-optimal procedures.

D. AIRCRAFT MODEL

1. Input Data

The sample data for the aircraft model is very similar to the engine data described previously. Each row of T_1 is associated with a particular type of aircraft and type of work. The production vector Y and the resource vector R are the same as described in the engine model. The data is listed in Table X.

The aircraft model consisted of a single objective function which was calculated as follows:

$$\text{OBJ} = P^T T_2 + C^T T_3 = \text{total cost per unit output of NORM}$$

(total cost = resource cost + penalty cost)

The remaining columns in Table X are identical in meaning to the engine model descriptions for Table VI.

2. Solution

The solution of the aircraft model is presented in Table XI. Due to the manner in which the data was aggregated the aircraft model consisted of only one process for each type of job in the production vector Y. The T_1 matrix consisted of 70 rows and 70 columns. Linear programming is not necessary to solve a problem of this type. There are no choices to make among processes, therefore, the activity level vector Z must be identical to the production vector Y (because T_1 is an identity matrix). The solution in Table XI does give an estimated total production cost associated with the production vector Y which can be used for budget estimates. A discussion concerning the aggregation problems for the aircraft data is presented in Chapter V. No sensitivity analysis was conducted on the aircraft model because the amounts of resources required at the optimal (unconstrained resources) solution also represent the minimum resources required for a feasible solution to the linear program. This result occurs because there is only one process for each job type in the production vector Y.

Table V
Penalty Costs

Aircraft Program

<u>Type Aircraft</u>	<u>Unit Cost</u>	<u>Service Life (months)</u>	<u>Penalty Costs (\$/day in shop)</u>
C-2A	\$10,742,000	105	280.29
E-2B	10,742,000	105	280.29
F-4B	2,756,000	80	94.38
RF-4B	2,699,000	96	77.02
F-4J	2,492,000	80	85.34
RF-8G	1,300,000	75	47.48
F-8H	1,352,000	54	68.59
F-8J	1,302,000	54	66.05
RH-3A	1,508,000	80	51.64
SH-3A	1,278,000	80	43.76
SH-3D	1,064,000	80	36.43
CH-46A	1,083,000	80	37.08
UH-46A	834,000	80	28.56
CH-46D	1,083,000	80	37.08
UH-46D	834,000	80	28.56
CH-46F	1,083,000	80	37.08
CH-53A	1,453,000	96	41.46
CH-53D	1,453,000	96	41.46

Table V - Penalty Costs (continued)

Engine Program *

<u>Type Engine</u>	<u>Unit Cost</u>	<u>Penalty Costs (\$/day in shop)</u>
J79-GE-8B	\$225,000	61.64
J79-GE-8C	225,000	61.64
J79-GE-10	180,000	49.32
T58-GE-8B	65,000	17.81
T58-GE-8F	65,000	17.81
T58-GE-10	65,000	17.81
T64-GE-6B	125,000	34.25
T64-GE-413	167,000	45.25
J57 (all models)	210,000	57.53
T56 (all models)	98,600	27.01

* a 10 year service life was assumed for all engines.

ROW NO. TYPE/WORK CODE PRODUCTION VECTOR (Y)

1	51/01	435.00
2	51/04	0.0
3	53/01	0.0
4	53/01	6675.00
5	53/04	0.0
6	55/01	3290.00
7	55/04	0.0
8	56/04	0.0
9	56/03	160.00
10	57/01	800.00
11	63/01	3500.00
12	63/04	0.0
13	65/01	3500.00
14	65/01	3600.00
15	65/01	1425.00
16	65/03	0.0
17	65/03	5075.00
18	65/03	0.0
19	65/04	3450.00
20	65/04	3920.00
21	65/04	0.0
22	65/04	5250.00
23	66/04	0.0
24	67/01	400.00
25	67/04	990.00
26	69/01	6580.00
27	69/03	2035.00
28	69/04	990.00
29	72/04	0.0
30	74/03	600.00
31	74/04	5100.00
32	73/03	0.0
33	75/03	1305.00
34	75/03	440.00
35	73/04	0.0
36	73/04	0.0
37	75/04	1860.00
38	75/04	270.00
39	81/01	4320.00
40	81/03	600.00
41	81/04	5985.00
42	82/03	8625.00
43	83/02	50700.00
44	83/02	0.0
45	83/02	31250.00
46	83/04	6930.00
47	84/01	16100.00

RESOURCE VECTOR (R)

ROW NO.	RESOURCE
R1	DMHR
R2	DML\$
R3	DOH\$

200000.00
2500000.00
1600000.00

Table VI. Engine Model Input Data

COLUMN NO.	OBJ1	OBJ2	OBJ3	T1	ROW	R1	R2	R3	T3
1	25	23	1	1	1	0	11	6	0
2	16	14	1	2	2	921	2530	926	0
3	20	17	1	3	3	843	3075	675	0
4	23	19	1	4	4	939	4815	674	0
5	21	18	1	5	5	856	1353	671	0
6	28	26	1	6	6	1962	15325	953	0
7	16	14	1	7	7	0	4750	526	0
8	41	39	12	8	8	0	719	471	0
9	58	45	13	9	9	1	369	19	0
10	35	33	2	10	10	1	423	3	0
11	20	18	2	11	11	1	024	8	0
12	31	29	2	12	12	0	585	3	0
13	40	35	1	13	13	0	858	14	0
14	36	30	1	14	14	1	825	7	0
15	37	33	1	15	15	1	643	7	0
16	37	35	1	16	16	1	465	9	0
17	38	35	3	17	17	1	595	9	0
18	38	37	3	18	18	1	076	9	0
19	38	34	3	19	19	1	071	8	0
20	38	28	4	20	20	0	307	2	0
21	38	34	3	21	21	1	564	7	0
22	37	34	2	22	22	1	020	6	0
23	35	32	2	23	23	1	070	9	0
24	32	29	2	24	24	0	558	0	0
25	32	44	2	25	25	0	372	2	0
26	32	55	3	26	26	0	327	5	0
27	32	58	4	27	27	0	239	6	0
28	32	74	6	28	28	0	165	9	0
29	37	73	4	29	29	1	194	8	0
30	37	52	8	30	30	1	963	3	0
31	27	22	4	31	31	1	483	9	0
32	26	22	4	32	32	1	959	5	0
33	26	22	4	33	33	1	235	4	0
34	25	22	4	34	34	1	257	2	0
35	29	25	3	35	35	0	722	5	0
36	28	19	3	36	36	0	366	8	0
37	29	24	4	37	37	0	355	7	0
38	31	27	4	38	38	0	163	6	0
39	31	29	1	39	39	0	883	8	0
40	20	19	1	40	40	1	082	6	0

Table VI. Engine Model Input Data (Continued)

COLUMN NO.	OBJ1	OBJ2	OBJ3	T1 ROW	R1	R2	R3	T3
41	17.258	15.761	12.484	29	0.583	8.152	4.088	0.083
42	13.158	27.723	1.434	30	1.601	5.898	18.528	0.104
43	32.001	20.157	1.854	31	1.114	10.119	8.528	0.088
44	32.332	35.389	1.563	32	1.083	19.171	7.596	0.075
45	32.332	22.337	1.543	33	1.082	17.992	8.095	0.134
46	24.841	22.733	1.503	34	0.975	13.347	7.490	0.084
47	20.555	18.069	1.186	35	0.983	15.588	7.064	0.123
48	25.665	24.163	1.135	36	0.983	13.598	7.143	0.084
50	28.008	30.658	1.118	37	0.910	13.998	6.655	0.063
51	31.499	30.379	1.111	38	0.910	18.230	7.472	0.063
52	20.871	18.650	1.105	39	0.903	15.380	6.609	0.107
53	22.874	20.966	1.104	40	0.926	18.990	6.949	0.107
54	22.874	21.168	1.104	41	0.926	8.690	6.949	0.092
55	28.178	21.479	1.104	42	0.926	14.631	6.252	0.095
56	34.230	26.719	1.138	43	0.926	16.072	9.252	0.078
57	34.230	23.046	1.138	44	0.884	16.589	7.163	0.070
58	26.276	23.935	1.124	45	1.093	18.505	8.304	0.131
59	26.547	27.586	1.124	46	1.121	9.811	8.021	0.110
60	29.557	27.440	1.124	47	1.150	12.774	8.710	0.149
61	29.081	25.440	1.124	48	1.150	19.785	8.710	0.108
62	29.081	25.542	1.124	49	1.108	10.537	8.095	0.101
63	29.081	25.590	1.124	50	1.080	17.377	8.470	0.064
64	29.081	25.590	1.124	51	1.080	6.977	8.170	0.056
65	29.081	25.590	1.124	52	1.080	9.417	6.505	0.040
66	24.064	22.614	1.124	53	1.008	9.417	8.105	0.032
67	26.064	22.614	1.124	54	1.013	10.213	7.859	0.029
68	26.064	24.068	1.124	55	0.978	11.529	7.633	0.041
69	26.064	23.113	1.124	56	0.978	10.449	6.758	0.048
70	14.036	23.113	1.124	57	0.701	11.255	5.777	0.037
71	23.044	22.084	1.124	58	0.962	8.771	7.483	0.037
72	23.044	22.084	1.124	59	0.962	9.157	7.564	0.037
73	23.044	22.084	1.124	60	1.022	7.807	7.564	0.034
74	23.044	22.084	1.124	61	1.022	10.134	7.564	0.034
75	23.044	22.084	1.124	62	1.022	10.165	7.564	0.032
76	23.044	22.084	1.124	63	1.022	9.912	6.893	0.032
77	23.044	22.084	1.124	64	1.022	10.165	7.814	0.085
78	23.044	22.084	1.124	65	1.022	6.506	7.259	0.085
79	23.044	22.084	1.124	66	1.022	6.506	8.136	0.095
80	23.044	22.084	1.124	67	1.022	6.506	10.001	0.076
81	23.044	22.084	1.124	68	1.022	7.066	7.140	0.066

Table VI. Engine Model Input Data (Continued)

$$\text{Objective Function} = P^T T_2 Z + C^T T_3 Z$$

	Optional Solution	Parametric Studies on Optional Solution		
		Minimizing DMHR Used	Minimizing DML\$ Used	Minimizing DOH\$ Used
Objective Function Value	5,227,836	5,379,854	5,364,833	5,419,475
Resource Cost	4,742,057	4,887,049	4,836,428	4,939,728
Penalty Cost	485,779	492,805	528,405	479,747
DMHR Used	187,917	183,674 *	196,311	185,617
DML\$ Used	2,215,889	2,401,905	2,122,367 *	2,471,487
DOH\$ Used	1,391,150	1,375,753	1,528,343	1,347,115 *

* represent minimum amount of resource required for a feasible solution (assuming other two resources are unlimited)

Table VII

Engine Model Solution for Total Cost Objective Function

$$\text{Objective Function} = P^T \cdot T_2 \cdot Z$$

	Optimal Solution	Parametric Studies on Optional Solution			
		Unconstrained Resources	Minimizing DMHR Used	Minimizing DML\$ Used	Minimizing DOH\$ Used
Objective Function Value	4,742,043	4,887,036	4,836,423	4,939,717	
Resource Cost	4,742,043	4,887,036	4,836,423	4,939,717	
Penalty Cost	485,779	492,805	528,405	479,747	
DMHR Used	187,917	183,674 *	196,311	185,617	
DML\$ Used	2,215,889	2,401,905	2,122,367 *	2,471,487	
DOH\$ Used	1,391,150	1,375,753	1,528,343	1,347,115 *	

* represent minimum amount of resource required for feasible solution (assuming other two resources are unlimited)

Table VIII

Engine Model Solution for Resource Cost Objective Function

$$\text{Objective Function} = C^T \cdot T_3 \cdot Z$$

	Optimal Solution Unconstrained Resources	Parametric Studies on Optimal Solution		
		Minimizing DMHR Used	Minimizing DML\$ Used	Minimizing DOH\$ Used
Objective Function Value	462,715	487,152	528,410	479,764
Resource Cost	5,028,894	4,986,177	4,836,428	4,939,728
Penalty Cost	462,715	487,152	528,410	479,764
DMHR Used	188,439	183,674 *	196,311	185,617
DML\$ Used	2,471,565	2,456,646	2,122,367 *	2,471,487
DOH\$ Used	1,419,158	1,420,141	1,528,343	1,347,115 *

* represent minimum amount of resource required for a feasible solution (assuming other two resources are unlimited)

Table IX

Engine Model Solution for Penalty Cost Objective Function

ROW NO.	TYPE/WORK CODE	PRODUCTION VECTOR (Y)
1	10/41	0.0
2	10/42	9300.00
3	11/32	0.0
4	11/33	12000.00
5	11/34	81200.00
6	21/11	0.0
7	21/21	93600.00
8	21/22	32800.00
9	21/41	0.0
10	21/62	0.0
11	22/13	23500.00
12	22/14	0.0
13	22/22	0.0
14	22/23	0.0
15	22/24	0.0
16	22/25	0.0
17	22/42	73200.00
18	22/43	85000.00
19	22/44	13800.00
20	22/45	70000.00
21	22/52	0.0
22	22/53	0.0
23	22/54	0.0
24	22/55	0.0
25	22/63	0.0
26	22/64	0.0
27	22/65	0.0
28	22/66	0.0
29	23/34	0.0
30	25/11	14000.00
31	25/21	0.0
32	25/22	0.0
33	25/61	0.0
34	26/11	0.0
35	26/12	0.0

Table X. Aircraft Model Input Data

ROW NO.	TYPE/WORK CODE	PRODUCTION VECTOR (Y)
36	26/21	0.0
37	26/61	0.0
38	26/62	0.0
39	27/12	0.0
40	27/22	0.0
41	27/23	0.0
42	27/61	0.0
43	27/63	0.0
44	31/20	0.0
45	32/22	4500.00
46	32/23	4200.00
47	32/24	0.0
48	33/21	0.0
49	33/23	0.0
50	34/33	0.0
51	34/34	34000.00
52	34/35	46800.00
53	34/36	0.0
54	35/12	0.0
55	35/22	4500.00
56	41/22	4400.00
57	41/23	0.0
58	41/43	0.0
59	42/22	32000.00
60	42/42	0.0
61	43/21	18000.00
62	44/23	0.0
63	45/22	0.0
64	48/21	0.0
65	48/22	14700.00
66	48/71	29400.00
67	48/72	0.0
68	48/82	0.0
69	49/21	44000.00
70	49/71	0.0

ROW NO.	RESOURCE	RESOURCE VECTOR (R)
R1	DMHR	800000.00
R2	DML\$	2000000.00
R3	DOH\$	5000000.00

Table X. Aircraft Model Input Data (Continued)

COLUMN NO.	OBJ	T1	ROW	R1	R2	R3	T3
1	17.941	1		1.0330	2.073	6.475	9.011
2	17.973	2		1.0592	2.847	6.046	9.010
3	18.422	3		1.0330	2.803	6.979	9.010
4	19.442	4		1.0388	2.832	7.283	9.009
5	18.672	5		1.0119	2.543	6.572	9.011
6	18.871	6		1.0255	2.973	6.572	9.007
7	17.125	7		1.0799	2.576	7.791	9.007
8	16.663	8		1.0799	2.435	6.791	9.007
9	14.961	9	0	1.0338	1.164	6.429	9.009
10	15.735	10		1.0338	2.400	6.486	9.008
11	15.513	11		0.997	2.973	5.931	9.012
12	16.677	12	3	1.014	2.973	6.352	9.012
13	15.487	13	4	1.059	2.950	6.376	9.008
14	15.275	14	5	0.979	1.361	6.087	9.009
15	15.823	15	6	1.014	2.463	6.254	9.010
16	16.093	16	7	1.026	2.353	6.485	9.008
17	15.661	17	8	0.997	1.642	7.148	9.008
18	15.629	18	9	1.052	1.952	6.553	9.009
19	15.944	19	10	1.052	2.038	6.562	9.010
20	16.721	20	11	1.020	2.983	6.577	9.008
21	16.217	21	12	1.026	2.443	6.590	9.008
22	15.619	22	13	1.034	2.021	6.304	9.009
23	15.758	23	14	1.038	2.615	6.770	9.008
24	16.223	24	15	1.088	2.208	6.514	9.008
25	15.223	25	16	0.862	3.374	5.148	9.011
26	15.000	26	17	1.022	2.812	7.239	9.007
27	18.003	27	18	1.185	2.374	6.321	9.006
28	16.958	28	19	1.005	2.812	5.299	9.015
29	11.791	29	20	0.783	1.240	6.514	9.011
30	16.791	30	21	0.959	2.403	5.495	9.010
31	16.050	31	22	1.018	2.571	6.144	9.012
32	14.020	32	23	0.868	2.867	5.537	9.016
33	16.943	33	24	1.091	2.907	6.677	9.014
34	16.553	34	25	1.028	2.461	6.787	9.014
35	15.980	35	26	0.979	2.161	6.787	9.014

Table X. Aircraft Model Input Data (Continued)

COLUMN NO.	OBJ	T1 ROW	R1	R2	R3	T3
36	15.101	36	0.943	2.297	6.315	0.010
37	16.364	37	0.993	2.542	6.998	0.010
38	19.732	38	1.222	2.932	7.482	0.011
39	15.867	39	1.026	2.292	6.931	0.018
40	13.214	40	0.842	2.724	5.931	0.009
41	17.017	41	1.215	1.508	7.534	0.010
42	16.355	42	1.071	2.788	6.507	0.010
43	17.678	43	1.204	2.498	7.209	0.011
44	15.284	44	1.055	2.827	6.409	0.015
45	17.915	45	1.153	2.848	7.573	0.014
46	14.519	46	1.140	2.948	8.212	0.014
47	17.515	47	0.771	3.669	5.590	0.011
48	13.930	48	0.865	2.539	4.798	0.012
49	20.948	49	1.395	1.700	6.377	0.019
50	15.541	50	1.020	2.478	5.050	0.012
51	13.731	51	0.853	1.111	5.595	0.012
52	16.193	52	1.057	2.332	6.735	0.014
53	16.073	53	1.048	2.331	6.616	0.013
54	15.174	54	0.942	2.318	6.449	0.013
55	17.049	55	0.962	3.870	6.394	0.013
56	16.030	56	1.021	3.392	6.084	0.014
57	16.755	57	0.924	1.846	6.717	0.013
58	16.370	58	1.013	2.847	6.362	0.014
59	16.303	59	1.041	2.336	7.042	0.014
60	14.423	60	0.857	3.053	5.626	0.012
61	16.065	61	0.954	3.356	6.483	0.015
62	16.021	62	0.888	0.516	6.111	0.013
63	20.321	63	1.072	4.617	7.545	0.014
64	19.364	64	1.082	5.577	7.545	0.008
65	16.849	65	0.889	4.672	6.345	0.009
66	18.359	66	0.957	5.921	6.123	0.012
67	17.534	67	1.035	3.545	5.956	0.010
68	15.430	68	0.963	4.131	6.662	0.009
69	16.447	69	1.018	3.136		
70		70				

Table X. Aircraft Model Input Data (Continued)

Table XI
Aircraft Model Solution
for Total Cost Objective Function

Optimal Solution with Unconstrained Resources

Objective Function Value	12,400,594
Resource Cost	11,691,151
Penalty Cost	709,443
DMHR Used	775,635
DML\$ Used	1,921,528
DOH\$ Used	4,983,956

V. CONCLUSIONS AND AREAS FOR FUTURE STUDY

A. CONCLUSIONS

The sample problem solutions in Chapter IV answered some basic questions concerning the operation of a NARF. In the beginning of this study, it was not known if tradeoffs existed between resources used by the NARF. The solutions in Table VII showed that the ranges of the resources used were rather limited for feasible solutions. For example, in Table VII the reduction in use of DMHR to a minimum resulted in a 2.3% decrease from the optimal unconstrained solution. Similarly minimizing DML\$ and DOH\$ produced resource reductions of 4.2% and 11.2% respectively. Associated with minimizing DMHR, DML\$ and DOH\$ (one at a time) the total cost of production increased approximately 2 to 3% in each case. This demonstrated that the available tradeoffs among resources are small in the linear economic model. This result was not unexpected because of the similarity among processes estimated for each type of work.

The total cost objective function is composed of two components, resource cost and penalty cost. In the sample problems considered the total cost was approximately 90% resource cost and 10% penalty cost. This fact caused the total cost optimal solution to be the same as the resource cost optimal solution. Alternate methods of determining penalty costs are discussed in Section B of this chapter.

The sample problems solved in Chapter IV predicted budget requirements for a specific calendar quarter, based on forecasted production requirements. To draw a meaningful conclusion about the validity of the model these results must be compared with the actual production work in that quarter and the actual quantities of resources consumed. This type of comparison should be made over a series of production periods of varying length to determine the accuracy of the model. This validation was not completed in time for inclusion in this thesis. Since this model is only a part of a continuing project at the Naval Postgraduate School, additional results are expected in the near future.

B. AREAS FOR FUTURE STUDY

1. Expanding Number of Observations

As mentioned in Chapter II and IV, special problems were encountered with the aircraft model sample data because of the small number of raw data observations. Based on discussions with NARF and MSDO personnel a decision was made to consider work done in different "cycles" (a cycle is the number of times the aircraft has been through the NARF for the same type of work) as different types of work. The resulting aircraft model had 70 separate processes with only 365 observations to estimate the processes. In comparison the engine model had 81 separate processes and 1532 observations. Forty-one out of 70 processes in the aircraft model had three or fewer observations. The engine

program had only 11 out of 81 processes with three or fewer observations. The magnitude of this problem could be reduced by increasing the number of observations in each model. However, an upper limit should be placed on the age of an observation to ensure the processes that are estimated reflect the current technology at the NARF.

2. Penalty Costs

As seen in Chapter IV the penalty costs had very little effect in determining the solution to the engine model. The reason was that the resource cost was at least five times as large as the penalty cost when the objective function was formulated. (See Table VI for examples). It could easily be argued that the present method used to determine the penalty costs does not approximate the opportunity cost (for the Navy) of keeping an engine (or aircraft in the shop for an extra day.

One alternate method by which the penalty cost might be computed is:

$$\text{penalty cost} = \frac{\begin{array}{c} \text{procurement cost} \\ + \\ \text{total maintenance cost over lifetime} \end{array}}{\text{lifetime}}$$

Certainly there is not a single procedure to determine penalty cost that cannot be criticized in some area. However, this problem must be addressed and resolved if an accurate cost-effectiveness analysis of WIPICS is to result.

3. Production Vector

In the linear economic model formulated in Chapter III the production vector (Y) is assumed as a given input to the model. In reality, the production demanded of the NARF each calender quarter is the result of a complex negotiation procedure between NAVAIRSYSCOM representatives and NARF representatives. Each component (Y_1) of the production vector may be considered a random variable whose value depends on the negotiation results. It is possible to construct a mathematical model of the negotiation procedures that would generate (predict) production vectors for use in the linear economic model. Further consideration should be given to a model of this type in lieu of using fixed production vectors based on historical data.

4. Management Constraints

One area in which extensions of the linear economic model would be beneficial is the incorporation of constraints for management practices. For example, there is a fixed manpower ceiling at the NARF for the permanent (employed at the NARF for more than one year) labor force. Suppose a given production vector (Y) utilizes the entire DMHR resource making the model infeasible. A temporary labor force could be hired from the surrounding community and be used to make up the deficit DMHR. The model becomes feasible.

Another possible extension exists in the pricing of labor. The management policy at the NARF could dictate a maximum allowable percentage of overtime per quarter. The overtime man-hours could be modeled as an additional constraint and priced according to current union contract agreements.

Further study is required to determine the effects of management decisions (or management constraints such as union contracts) on the linear economic model. Modifications and/or additional constraints may be necessary.

APPENDIX A

Correlation Program for Raw Data

- A. Purpose: The purpose of this program is to calculate and print a table of correlation coefficients between NORM, DMHR, DLB\$, DML\$, DOH\$, NIFR and NDAY. A table of means and standard deviations is printed for each of the above variables.
- B. Inputs: The first card is a control card which is then followed by the raw data cards. All fields are right adjusted unless otherwise specified. The abbreviation "CC" refers to card columns and will be used in all Appendices. The format of the cards follows:

Control Card: CC 1-4 number of raw data cards

CC 5-8 0001 for aircraft

0002 for engines

Raw data card: CC 1-2 engine/aircraft code

CC 3 blank

CC 4-10 Identification number

CC 11 blank

CC 12-13 work code

CC 14 blank

CC 15-18 induction date

CC 19 blank

CC 20-23 production date

CC 24 blank
CC 25-29 NORM
CC 30 blank
CC 31-35 airframe change man-hours (blank
for engine cards)
CC 36 blank
CC 37-41 DMHR
CC 42 blank
CC 43-48 DLB\$
CC 49 blank
CC 50-55 DML\$
CC 56 blank
CC 57-62 DOH\$
CC 63 blank
CC 64-68 NIFR

The NIFR is expressed as an integer but the last two digits are cents. For example a NIFR of 1482 means \$14.82. All other dollar values are in whole dollars.

C. Outputs: A table of correlation coefficients and a table of means and standard deviations for each variable are printed.

D. Special Notes:

(1) Subroutines CORRE, LOC and MSTR are from the IBM Scientific Subroutine Package. (Input to the CORRE subroutine is a linear array vice a matrix to simplify dimension requirements).

(2) The maximum number of data cards that the program can handle is 1600. Capacity may be increased by changing the DIMENSION and DATA statements.


```

SUBROUTINE CORRE (N,M,IO,X,XBAR,STD,RX,R,B,D,T)
DIMENSION X(I),XBAR(I),STD(I),RX(I),R(I),B(I),D(I),T(I)
DO 100 J=1,M
  B(J)=0.0
  T(J)=0.0
  K=(M*M+M)/2
DO 102 I=1,K
  R(I)=0.0
  FN=N
  L=0
DO 105 DO 108 J=1,M
  DO 107 I=1,N
  L=L+1
  T(J)=T(J)+X(L)
DO 107 XBAR(J)=T(J)
DO 108 T(J)=T(J)/FN
DO 115 I=1,N
  JK=0
  L=I-N
DO 110 J=1,M
  L=L+N
  D(J)=X(L)-T(J)
DO 110 B(J)=B(J)+D(J)
DO 115 J=1,M
  DO 115 K=1,J
  JK=JK+1
  R(JK)=R(JK)+D(J)*D(K)
DO 115 JK=0
DO 210 J=1,M
  XBAR(J)=XBAR(J)/FN
DO 210 K=1,J
  JK=JK+1
DO 210 R(JK)=R(JK)-B(J)*B(K)/FN
DO 210 JK=0
DO 220 J=1,M
  JK=JK+J
DO 220 STD(J)=SQRT(ABS(R(JK)))
DO 230 J=1,M
  DO 230 K=J,M
  JK=J+(K-K)/2
  L=M*(J-1)+K
  RX(L)=R(JK)
  L=M*(K-1)+J
  RX(L)=R(JK)
  IF(STD(J)*STD(K)) 225, 222, 225
DO 222 R(JK)=0.0

```



```

GO TO 230
R(JK)=R(JK)/(STD(J)*STD(K))
225 CONTINUE
230 FN=SQRT(FN-1.0)
DO 240 J=1,M
240 STD(J)=STD(J)/FN
L=-M
DO 250 I=1,M
L=L+M+1
250 R(I)=RX(L)
RETURN
END

SUBROUTINE LOC(I,J,IR,N,M,MS)
IX=I
JX=J
IF(MS-1) 10,20,30
IF(IR=N*(JX-1)+IX
10 GO TO 36
20 IF(I-X-JX) 22,24,24
22 IRX=IX+(JX-JX-JX)/2
24 GO TO 36
24 IRX=JX+(IX-IX-IX)/2
30 GO TO 36
30 IRX=0
32 IF(I-X-JX) 36,32,36
32 IRX=IX
36 IR=IRX
RETURN
END

SUBROUTINE MSTR(A,R,N,MSA,MSR)
DIMENSION A(1),R(1)
DO 20 I=1,N
DO 20 J=1,N
IF(MSR) 5,10,5
5 IF(I-J) 10,10,20
10 CALL LOC(I,J,IR,N,MSR)
15 IF(IR)=0,0
15 CALL LOC(I,J,IA,N,MSA)
18 IF(IA) 20,20,18
18 R(IR)=A(IA)
20 CONTINUE
RETURN
END

```


APPENDIX B

Cluster Data Program

A. Purpose: The purpose of this program is to calculate and provide a punched card deck for input to the distance matrix program in Appendix C. Each input data card is normalized to a unit vector for the five variables NORM, DMHR, DML\$, DOH\$ and NDAY. Then each variable is standardized by the following transformation:

$$\frac{x_{ij} - \mu_j}{\sigma_j} \quad \text{where } x_{ij} = i^{\text{th}} \text{ observation on the } j^{\text{th}} \text{ variable}$$

$i = 1, \dots, n$
 $j = 1, \dots, 5$
 $n = \text{number of data cards}$
 $\sigma_j = \text{standard deviation of the } j^{\text{th}} \text{ variable}$
 $\mu_j = \text{mean of the } j^{\text{th}} \text{ variable}$

B. Inputs: The first card is a control card which is followed by a deck of aggregated data cards. The aggregated data cards are described in Appendix F.

Control Card: CC 1-3 number of aggregated data cards

Aggregated data card: the format is specified in Appendix F.

C. Outputs: Listings of input data, normalized data and normalized/standardized data and a deck of punched cards

for input to the distance matrix program in Appendix C are provided. The punched output deck is in the following format:

CC 1-2	engine/aircraft type code
CC 3	blank
CC 4-10	Identification code
CC 11	blank
CC 12-13	work code
CC 14-24	NORM
CC 25-35	DMHR
CC 36-46	DML\$
CC 47-57	DOH\$
CC 58-68	NDAY

D. Special Notes:

- (1) The maximum number of aggregated data cards is 150. This capacity may be increased by changing the appropriate DIMENSION and DATA statements.
- (2) This program may be modified to handle raw data cards by changing FORMAT statement number 9001.


```

2 SCNT=SCNT+1.0
DO 6 I=1,NV
  IJ=IJ+NO
  TOTAL(I)=TOTAL(I)+A(IJ)
  IF(A(IJ)-VMIN(I)) 3,4,4
3 4 VMIN(I)=A(IJ)
  IF(A(IJ)-VMAX(I)) 6,6,5
5 6 VMAX(I)=A(IJ)
  SD(I)=SD(I)+A(IJ)*A(IJ)
7 CONTINUE
  IF (SCNT) 8,8,9
8 IER=1
DO 85 I=1,NV
  VMIN(I)=-1.0E75
  VMAX(I)=1.0E75
  SD(I)=1.0E75
  AVER(I)=1.0E75
85 CONTINUE
  GO TO 15
9 DO 10 I=1,NV
10 AVER(I)=TOTAL(I)/SCNT
  IF (SCNT-1.0) 13,11,13
11 IER=2
DO 12 I=1,NV
12 SD(I)=0.0
  GO TO 15
13 DO 14 I=1,NV
14 SD(I)=SQRT(ABS((SD(I)-TOTAL(I))*TOTAL(I)/SCNT)-(SCNT-1.0)))
15 RETURN
END

```


APPENDIX C

Distance Matrix Program

- A. Purpose: To provide a punched card deck of squared Euclidian distances between each pair of observation vectors (i.e. normalized and standardized input data cards). The distance matrix is a required input for the clustering program in Appendix D.
- B. Inputs: A control card is required followed by a deck of normalized and standardized (N&S) cards. The formats are as follows:
- Control Card: CC 1-3 number of N&S cards
- N&S Deck: format is specified in Appendix B.
- C. Outputs: The outputs are listings of input data and the squared Euclidian distance matrix. The distance matrix is stored in a linear array that corresponds to the lower half of the matrix. The listing and data cards of the distance matrix are printed and punched in the linear array format. Since a complicated procedure is required to locate the distance between any particular pair of observation vectors the format will not be specified in detail. Each distance matrix output card contains 10 distances. The total number of distances calculated and punched is:

$$\frac{n \times (n-1)}{2} \quad \text{where } n = \text{number of N\&S cards contained in the input deck.}$$

D. Special Notes:

(1) The output deck must be kept in the exact order in which it is punched. The position of each number in the linear array determines which pair of observation vectors were used to compute that particular distance value.

(2) The maximum number of N&S input data cards is 200. This capacity may be increased by changing the DIMENSION statement.

APPENDIX D

Clustering Program

A. Purpose: The purpose of this program is to cluster together individual observations and groups of observations that are mathematically similar. Further discussion on clustering can be found in Ref. 8. The program begins by considering each input vector (observation) as a cluster with one observation. The two "closest" (based on Euclidian distance) clusters are combined into a single cluster and the distance from this new cluster to all other clusters is recomputed and the distance matrix is adjusted. The clustering continues until all observations are in a single cluster.

The program provides a detailed listing of the clusters that are combined at each step and at the users option the program will provide a detailed description of each cluster. A deck of punched cluster "descriptions" is produced at intervals specified by the user. A cluster "description" consists of the number of clusters, the number of observation vectors (i.e. number of elements) in each cluster and an ordered vector of observation numbers (an observation number is the number assigned to each observation vector based on its position when the distance matrix was produced). For example:

Suppose we have 6 observation vectors clustered as follows

<u>Cluster no.</u>	<u>No. of observation vector</u>
1	1,3
2	2
3	5,6,4

The cluster description would be

number of clusters = 3

number of observations in each cluster = 2,1,3

vector of observation numbers = 1,3,2,5,6,4,

B. Inputs: A control card and the distance matrix produced by Appendix C are required. The formats are as follows:

Control Card	CC 1-3	number of observation vectors
	CC 4-6	stage at which a complete cluster description begins in the output listing. . (stage is the number of clusters currently existing in the program)
	CC 7-14	Beta value (See Ref. 8). The value -0.25000 used in all clustering done in this thesis.
	CC 15-17	KM1
	CC 18-20	KM2
	CC 21-23	KM3

} See below

Cluster "descriptions" are punched starting at Stage KM1 and continuing to Stage KM2 in increments of KM3. For example: if KM1 = 16

KM2 = 12

KM3 = 2

then cluster "descriptions" will be punched at stages 16, 14 and 12.

- C. Outputs: A listing describing clustering as discussed in Part A is provided. A punched deck of cluster descriptions as specified by the control card is provided. The punched output format is as follows:

First card: CC 1-3 number of clusters

Second group of cards (as many as needed): number of observation vectors in each cluster with each card having a maximum of 20 numbers, each right each adjusted in a 3 column field.

Final group of cards (as many as needed): ordered vector of observation numbers as described in Part A. The format is the same as for the second group.

- D. Special Notes:

(1) The maximum number of observation vectors is 100.

(2) The user must decide at what point further clustering ceases to be useful. The computer algorithm automatically proceeds until all observations are in a single cluster.


```

*****
CLUSTER ANALYSIS BY HEIRARCHICAL FLEXIBLE METHOD
WITH A PUNCH OPTION FOR CLUSTER DESCRIPTIONS
*****
DIMENSION D(5000), NAME(100), NUMB(100), D1(100), D2(100),
1 MCLUS(100), LOCN(101), NSTO(100)
READ(5,17) N,XNCLUS,BETA,KM1,KM2,KM3
FORMAT(2I3,F8.3,3I3)
NX=N
IF(N.LE.100) GO TO 50
WRITE(6,27)
FORMAT(6T00 MANY ITEMS')
STOP
NN=N*(N-1)/2
ALPHA=(1.0-BETA)/2.0
DO 51 I=1,N
NAME(I)=1
MCLUS(I)=1
LOCN(I)=1
NUMB(I)=1
LOCN(N+1)=N+1
WRITE(6,57) N, ALPHA, BETA
FORMAT(1FLEXIBLE HIERARCHICAL CLUSTERING ALGORITHM',/,I4,
1 , ITEMS',7X,'ALPHA =',F6.3,7X,'BETA =',F7.3,//)
READ(5,67) (D(K),K=1,NN)
FORMAT(10F8.0))
START NEXT ITERATION BY FINDING SMALLEST DISTANCE
DMIN=10000.0
DO 100 I=2,N
KK={I-2}*(I-1)/2
II=I-1
DO 100 J=1,II
K=KK+J
IF(D(K).GE.DMIN) GO TO 100
DMIN=D(K)
IMIN=I
JMIN=J
KMIN=K
CONTINUE
IMPL=IMIN+1
IMMI=IMIN-1
JMPL=JMIN+1
*****

```



```

JMM1=JMIN-1
NM1=N-1
IF(JMIN.EQ.IMIN-1) GO TO 1045
L=LOCN(JMIN+1)
LL=LOCN(IMIN)-1
DO 101 I=LL,LL
  NS(I)=MCLUS(I)
101  N1=NUMB(IMIN)
  DO 102 I=1,N1
    MCLUS(L+I-1)=MCLUS(LL+I)
102  DO 103 I=L,LL
    MCLUS(N1+I)=NSTO(I)
103  DO 104 I=JMP1,IMM1
    LOCN(I)=LOCN(I)+N1
104  DO 105 I=IMIN,N
    LOCN(I)=LOCN(I+1)
105  C
C  GROUPS IMIN AND JMIN WILL BE MERGED
C
NUMB(JMIN)=NUMB(JMIN)+NUMB(IMIN)
WRITE(6,107) N,NAME(JMIN),NAME(IMIN),NAME(JMIN),NUMB(JMIN)
107  FORMAT('OAT STAGE',I4,' MERGE GROUPS',I4,' AND',I4,' CALLING RESULT
C  ITING GROUP',I4,' WITH',I4,' ELEMENTS,')
C
C  EXTRACT D1 = DISTANCE VECTOR FOR JMIN GROUP
C  D2 = DISTANCE VECTOR FOR IMIN GROUP
C
K=(JMIN-2)*(JMIN-1)/2
IF(JMIN.EQ.1) GO TO 185
DO 180 J=1,JMM1
  D1(J)=D(K+J)
180  D1(JMIN)=0.0
185  DO 190 I=JMP1,N
  K=((I-1)*(I-2)/2)+JMIN
  D1(I)=D(K)
190  K=IMIN-2*(IMIN-1)/2
  DO 200 J=1,IMM1
  D2(J)=D(K+J)
200  D2(IMIN)=0.0
  IF(IMIN.EQ.N) GO TO 215
  DO 210 I=JMP1,N
  K=((I-2)*(I-1)/2)+IMIN
  D2(I)=D(K)
210  C
C  COMPUTE D3 = DISTANCE VECTOR FOR MERGED GROUP - PLACE IN D1
C
DO 220 I=1,N
215  D1(I)=ALPHA*(D1(I)+D2(I))+BETA*DMIN
220

```



```

C      INSERT D1 INTO MATRIX IN JMIN POSITION
C
      K=(JMIN-2)*(JMIN-1)/2
      IF(JMIN.EQ.1) GO TO 235
      DO 230 J=1,JMM1
      D(K+J)=D1(J)
230   DO 240 I=JMP1,N
235   K=((I-2)*(I-1)/2)+JMIN
240   D(K)=D1(I)
C      REPACK MATRIX TO OMIT IMIN POSITION
C
      IF(IMIN.EQ.N) GO TO 280
      DO 250 I=IMIN,NM1
      KK=(I-2)*(I-1)/2
      KKK=KK+I-1
      DO 250 J=1,JMM1
      D(KK+J)=D(KKK+J)
250   IF(IMIN.EQ.N-1) GO TO 265
      DO 260 I=IMPL,NM1
      KK=((I-2)*(I-1)/2)
      KKK=KK+I
      I=I-1
      DO 260 J=IMIN,I
      D(KK+J)=D(KKK+J)
C      PACK NAME AND NUMBER LISTS
C
      DO 270 I=IMIN,NM1
      NAME(I)=NAME(I+1)
      NUMB(I)=NUMB(I+1)
      N=N-1
      IF(KM1.LI.KM3) GO TO 281
      IF(N.EQ.KM1) GO TO 300
      IF(N.GT.NCLUS) GO TO 70
      WRITE(6,287) N
      FORMAT('OSTAGE',I4)
      DO 290 I=1,N
      L=LOCN(I)
      LL=LOCN(I+1)-1
      WRITE(6,297) NAME(I),(MCLUS(K),K=L,LL)
290   FORMAT('GROUP',I4,I10,I9I4,/(16X,20I4))
297   IF(N.GT.1) GO TO 70
      STOP

```

```

C      PUNCH CLUSTER DESCRIPTIONS
C      STARTING AT KM1 ENDING AT KM3 IN INCREMENTS OF KM2

```



```

C 300 WRITE (7,301) N
301 FORMAT (I3)
302 WRITE (7,302) (NUMB(I),I=1,N)
    FORMAT (20I3,20X)
    WRITE (7,302) (MCLUS(I),I=1,NX)
    KMI=KMI-KM2
    GO TO 281
END

```


APPENDIX E

Cluster Reallocation Program

- A. Purpose: This program ensures that each observation vector is assigned to the closest group centroid calculated from a cluster description supplied by the clustering Program in Appendix D. The program takes the normalized and standardized data cards and based on a specified cluster description a group centroid is calculated for each cluster. Each observation vector is then assigned to the closest centroid based on Euclidian distance. If any observation vector moves to a different cluster from its present assignment then the group centroids are recalculated and the observation vectors are again assigned to the closest group centroid. This reallocation process continues until a stable configuration is reached (i.e. no observation vector shifts clusters).
- B. Inputs: A control card is followed by the normalized and standardized data deck then the cluster description(s). The formats are as follows:
- Control card: CC 1-3 number of N&S data cards
- N&S Data Deck: format is the same as specified in Appendix B.
- Cluster Descriptions: format is the same as specified in Appendix D.
- C. Outputs: The normalized and standardized data is printed along with the initial cluster description. The program

then prints a series of cluster centroids and cluster descriptions until a stable configuration is reached. Then a deck of reallocated cluster descriptions is punched. The reallocated cluster descriptions have the same format as specified in Appendix D.

D. Special Notes:

(1) The program is set to handle multiple cluster descriptions. Place any additional cluster descriptions behind the first one.

(2) The maximum number of N&S data cards is 100. The DIMENSION statement may be changed to accomodate larger capacity.

(3) The maximum number of clusters that can be specified in a cluster description is 50. This capacity may be changed in the DIMENSION statement.

(4) Normally about 5% or less of the observation vectors will change clusters. If the percentage exceeds this limit then an input error or a very unstable cluster configuration may have caused the problem. The results should be carefully checked before continuing.


```

*****
K      MEAN CLUSTER REALLOCATION SYSTEM
      OUTPUT IS A PUNCHED DECK OF REALLOCATED CLUSTERS

*****
DIMENSION X(5,100),MCLUS(100),LOCN(101),NAME(100),NUMB(100),
1 CENTR(5,50),ID(100)
WRITE (6,95000)

*****
READ INPUT DATA

READ(5,7) N
FORMAT(1I3)
READ(5,1)((X(J,I),J=1,5),I=1,N)
FORMAT(1I3X,5F11.5,12X)
READ(5,7,END=9999) NCLUS
READ(5,37)(NUMB(I),I=1,NCLUS)
FORMAT(20I3,20X)
READ(5,37)(MCLUS(I),I=1,N)
LOCN(1)=1
DO 50 K=1,NCLUS
   LOCN(K+1)=LOCN(K)+NUMB(K)
   NAME(K)=MCLUS(LOCN(K))
DO 60 K=1,NCLUS
   NK=NUMB(K)
   L=LOCN(K)-1
DO 60 I=1,NK
   MC=MCLUS(L+I)
   ID(MC)=K

*****
WRITE CLUSTER

WRITE(6,287) NCLUS
FORMAT('OSTAGE',14)
DO 290 J=1,NCLUS$
L=LOCN(1)
LL=LOCN(I+1)-1
WRITE(6,297) I,NAME(I),(MCLUS(K),K=L,LL)
FORMAT(15,'GROUP',14,I10,19I4,/,16X,20I4))

*****
COMPUTE GROUP CENTROIDS

DO 100 K=1,NCLUS
DO 100 J=1,5
CENTR(J,K)=0.0

*****

```



```

DO 150 K=1,NCLUS
NK=NUMB(K)
ZNK=NK
L=LOCN(K)-1
DO 140 I=1,NK
MC=MCLUS(L+I)
DO 140 J=1,5
CENTR(J,K)=CENTR(J,K)+X(J,MC)
DO 145 J=1,5
CENTR(J,K)=CENTR(J,K)/ZNK
WRITE(6,147)
FORMAT(1,5)
WRITE(6,157)(K,NAME(K),(CENTR(J,K),J=1,5),K=1,NCLUS)
FORMAT(15,1, GROUP,14,CENTROID,5F10.3)
WRITE(6,147)
C      ASSIGN EACH POINT TO NEAREST CENTROID
C
ISW=0
DO 700 I=1,N
DMIN=10000.0
DO 600 K=1,NCLUS
D=0.0
DO 550 J=1,5
DXJ=(X(I)-CENTR(J,K))
D=D+DXJ**2
IF(D.GE.DMIN) GO TO 600
DMIN=D
KMIN=K
CONTINUE
IF(ID(I).NE.KMIN) ISW=1
ID(I)=KMIN
IF(ISW.EQ.0) GO TO 1000
C      DEFINE NEW CLUSTERING
C
KSKIP=0
LOCN(1)=1
DO 850 K=1,NCLUS
KK=K-KSKIP
NUMB(KK)=0
L=LOCN(KK)-1
DO 800 I=1,N
IF(ID(I).NE.K) GO TO 800
NUMB(KK)=NUMB(KK)+1
NN=L+NUMB(KK)
MCLUS(NN)=I

```



```

800 ID(I)=KK
CONTINUE
IF(NUMB(KK).EQ.0) GO TO 820
LOCN(KK+1)=LOCN(KK)+NUMB(KK)
GO TO 850
820 KSKIP=KSKIP+1
WRITE(6,827) K,NAME(K)
827 FORMAT(15,' GROUP',14,' HAS DISAPPEARED.')
850 CONTINUE
NCLUS=NCLUS-KSKIP
DO 900 K=1,NCLUS
L=LOCN(K)
900 NAME(K)=MCLUS(L)
C
C GO BACK AND SEE IF ANY OTHER POINTS WANT TO SHIFT CLUSTERS
C
C GO TO 70
C
C PUNCH REALLOCATED CLUSTER DESCRIPTION
C
1000 WRITE(6,9500)
9500 FORMAT(11,'/')
WRITE(7,9501) NCLUS
9501 FORMAT(13)
WRITE(7,9502) (NUMB(I),I=1,NCLUS)
9502 FORMAT(20I3,20X)
WRITE(7,9502) (MCLUS(I),I=1,N)
C
C GO BACK AND REALLOCATE ANY REMAINING CLUSTER DESCRIPTIONS
C
9999 GO TO 20
STOP
END

```


APPENDIX F

Aggregation Program

- A. Purpose: This program combines groups of raw data cards into aggregated data cards. A listing is provided for the new aggregated data. The aggregation procedure consists of calculating a numerical average for each variable (excluding airframe change man-hours on aircraft raw data cards) on the raw data card. Two additional fields are calculated and punched into the new cards: NDAY and NOBS (number of raw data cards that are combined to produce the aggregated data card). These aggregated data cards are used as input requirements for programs in Appendices B, G, K and L.
- B. Inputs: A series of control cards are required. Each control card must be the first card of the group to be aggregated. The control card is punched in CC 1-3 with the exact number of raw data cards following it. The raw data cards are in the format specified in Appendix A. The input deck as described is called the preaggregation deck. It is used as an input deck for the program in Appendix J. Once this deck is created it should be kept in addition to the aggregated data cards. (Note: the control cards are referred to as I3 separator cards in the program)

C. Outputs: The output consists of a reformatted raw data card with two additional fields, NDAY and NOBS. These new cards are referred to as aggregated data cards. (Each aggregated data card is an estimation of a NARF process.) The program provides a listing of the aggregated data cards. The aggregated data card format follows:

CC 1-2	Aircraft/engine type
CC 3	blank
CC 4-10	identification code
CC 11	blank
CC 12-13	work type
CC 14-22	NORM
CC 23-31	DMHR
CC 32-40	DLB\$
CC 41-49	DML\$
CC 50-58	DOH\$
CC 59-67	NIFR
CC 68-76	NDAYS
CC 77-80	NOBS

D. Special Notes:

(1) The maximum number of control cards is 150. This capacity may be increased by the change of the DIMENSION and DATA statements of the program.

(2) The first 13 card columns of the first raw data card will become an "identifier" and are transferred to the aggregated data card.


```

*****
C      AGGREGATION PROGRAM FOR RAW DATA ( ENGINE OR AIRCRAFT )
C
C      INPUT DATA:
C      (1) RAW DATA CARDS WITH I3 SEPARATOR CARDS
C
*****
C      DIMENSION A(150),B(150),C(150),D(150),E(150),F(150),G(150)
C      DIMENSION IB(150),AB(150),KB(150),IH(150),S(8)
C      REAL*8 AB
C      INTEGER*2 IB
C      DATA A,B,C,D,E,F,G/1050*0.0/
C      DATA S,'NORM','DMHR','DLB$','DML$','DOH$','NIFR','NDAY','NOBS'/
C      WRITE (6,9500) S
C      FORMAT ('1,/,17X,'IDENTIFICATION',A10,4A12,IX,2A12,A10,/)
C      9500      I=0
C      1000      I=I+1
C
C      READ INPUT DATA FOR GROUP TO BE AGGREGATED
C
C      9000      READ (5,9000,END=9999) NN
C      9000      FORMAT (I3)
C      9000      IF (NN.EQ.1) GO TO 6000
C
C      FIRST CARD WILL CONTAIN IDENTIFICATION FOR THE GROUP
C
C      9001      READ (5,9001) IB(1),AB(1),KB(1),ID,JD,AX,BX,CX,DX,EX,FX
C      9001      FORMAT (I2,A8,A3,2I5,F6.0,6X,F6.0,3F7.0,F6.2)
C      9001      A(1)=A(1)+AX
C      9001      B(1)=B(1)+BX
C      9001      C(1)=C(1)+CX
C      9001      D(1)=D(1)+DX
C      9001      E(1)=E(1)+EX
C      9001      F(1)=F(1)+FX
C      9001      NDAYS=JD-ID
C      9001      IF (NDAYS.GE.635) NDAYS=NDAYS-635
C      9001      G(1)=G(1)+FLOAT(NDAYS)
C      9001      IH(1)=NN
C
C      NOW READ THE REST OF GROUP AND COMPUTE AVERAGES
C
C      DO 1500 J=2,NN,1
C      1500      READ (5,9002) ID,JD,AX,BX,CX,DX,EX,FX
C      1500      FORMAT (I2X,2I5,F6.0,6X,F6.0,3F7.0,F6.2)
C      1500      A(I)=A(I)+AX

```



```

B(I)=B(I)+BX
C(I)=C(I)+CX
D(I)=D(I)+DX
E(I)=E(I)+EX
F(I)=F(I)+FX
NDAYS=JD-ID
IF (NDAYS.GE.635) NDAYS=NDAYS-635
G(I)=G(I)+FLOAT(NDAYS)
CONTINUE
1500
  A(I)=A(I)/FLOAT(NN)
  B(I)=B(I)/FLOAT(NN)
  C(I)=C(I)/FLOAT(NN)
  D(I)=D(I)/FLOAT(NN)
  E(I)=E(I)/FLOAT(NN)
  F(I)=F(I)/FLOAT(NN)
  G(I)=G(I)/FLOAT(NN)
C
C GO BACK FOR NEXT GROUP TO BE AGGREGATED
C
C GO TO 1000
C
C LOOP FOR SINGLE CARD GROUPS
C
6000 READ (5,9001) IB(I),AB(I),KB(I),ID,JD,A(I),B(I),C(I),D(I),E(I),
1 F(I)
NDAYS=JD-ID
IF (NDAYS.GE.635) NDAYS=NDAYS-635
G(I)=FLOAT(NDAYS)
IH(I)=NN
C
C GO BACK FOR NEXT GROUP TO BE AGGREGATED
C
C GO TO 1000
C
C PRINT AND PUNCH AGGREGATED DATA CARDS
C
9999 LL=I-1
DO 2000 J=1,LL,1
  IF (J.EQ.71) WRITE (6,9500) S
  WRITE (6,9501) J,IB(J),AB(J),KB(J),A(J),B(J),C(J),D(J),E(J),
1 F(J),G(J),IH(J)
9501 FORMAT (' ',10X,I2,5X,I2,A8,A3,7F12.2,I8)
  WRITE (7,9502) IB(J),AB(J),KB(J),A(J),B(J),C(J),D(J),E(J),
1 F(J),G(J),IH(J)
9502 FORMAT (' I2,A8,A3,7F9.2,I4)
2000 CONTINUE
      STOP
      END

```


APPENDIX G

Dominance Program for Aggregated Data

- A. Purpose: The purpose of this program is to take aggregated data cards as an input and then display in a matrix the dominance relationships between the data cards. Recall that each aggregated data card represents an estimated process for the NARF. The specified input/output variables (in Chapter 2) are read from the input deck and then each process is converted to a unit output. The dominance matrix is printed and can be inspected for dominance among processes with the same output. The procedure to eliminate the dominance is described in Chapter 2.
- B. Inputs: The program requires a series of control cards to be inserted among the aggregated data cards. The control cards are punched with the number of aggregated data card following them (and prior to the next control card) in card columns 1-3. These control cards cause the aggregated data cards to be read in small groups thereby reducing the size of the dominance matrix. The control card should contain a number between 10 and 20 for most groups. For example, if we have 72 aggregated data cards then six control cards with 12 punched in CC 2-3 would suffice. However, the user must ensure that all processes with the same output are contained in the same control

card group. The dominance matrix is only calculated for those processes in the same group.

C. Outputs: The output consists of a listing of the aggregated data group (input/output variables only) and a listing of the unit output processes associated with each data card in the group. The dominance matrix is printed with the above listings. Each new group is started on a new page for ease of reference. The dominance matrix consists of three symbols defined as follows:

- (1) - means there is no dominance relationship between process A and process B (A and B are defined below)
- (2) X means that process A is dominated by (i.e. strictly greater than) process B
- (3) O means that process A dominates (i.e. strictly less than) process B.

Each symbol is in a particular row and column of the dominance matrix. (the column numbers are the same as the row numbers since the dominance matrix is always a square matrix.) "A" is the row number of the symbol and "B" is the column number of the symbol.

D. Special Notes: None.


```

199 CONTINUE
    WRITE(6,1047)
    L=STRL
C
C COMPUTE AND WRITE THE DOMINANCE MATRIX
C
DO 600 I=1,N
DO 500 J=1,N
    IOUT(J)=IDASH
    IF(I.EQ.J) GO TO 490
    IF((X(2,J).LE.X(2,I)).AND.(X(3,J).LE.X(3,I)).AND.(X(4,J).LE.X(4,I)
- (X(5,J).LE.X(5,I)).AND.(X(3,I).LE.X(3,J)).AND.(X(4,I).LE.X(4,J)).AND.(X(5,I).LE.X(5,J))
- (X(2,I).GE.X(2,J)).AND.(X(3,I).GE.X(3,J)).AND.(X(4,I).GE.X(4,J)).AND.(X(5,I).GE.X(5,J))
    GO TO 500
    IOUT(J)=ISTR
490 CONTINUE
500 WRITE(6,507) L,(IOUT(K),K=1,N)
507 FORMAT(16,2X,100A2)
    L=L+1
600 CONTINUE
C
C GO BACK FOR ANOTHER GROUP OF DATA CARDS
C
GO TO 5
9999 STOP
END

```


APPENDIX H

Listing of Aggregated Aircraft Data

The following listing provides the values of the aggregated data cards used in the aircraft model. The columns are as follows:

- (1) aircraft code
- (2) identification code
- (3) work code
- (4) NORM
- (5) DMHR
- (6) DLB\$
- (7) DML\$
- (8) DOH\$
- (9) NIFR
- (10) NDAY
- (11) NOBS

The format of these cards is described in Appendix F.

31	621	2576	20	5125	00	895	75	29267	75	14474	00	32846	00	58	4
32	148040	147146	223	4500	00	5188	00	30286	00	21813	00	38578	00	42	1
33	147144	149704	224	4500	00	4423	00	29705	00	16512	00	30289	00	12	1
34	149704	152154	233	4400	00	3394	00	20322	00	11171	00	25153	00	16	1
35	152154	155190	233	4400	00	3820	00	21190	00	11478	00	25113	00	07	1
36	155190	158175	233	4400	00	3975	00	22012	00	7062	00	28059	00	3	1
37	158175	161200	233	4520	00	5081	133	24223	366	10925	638	32930	355	44	1
38	161200	164237	233	4520	00	4677	00	30938	363	19335	666	32939	355	51	1
39	164237	167277	233	4520	00	9577	00	56719	390	35353	400	32939	355	33	1
40	167277	170300	233	4520	00	4041	00	23549	390	97135	700	27086	355	33	1
41	170300	173341	233	4520	00	4593	00	28356	00	17415	700	28774	355	33	1
42	173341	176384	233	4520	00	4313	00	26762	00	14922	700	26769	355	33	1
43	176384	179425	233	4520	00	4805	00	27975	00	19598	911	34929	455	33	1
44	179425	182468	233	4520	00	4051	645	25045	911	12987	911	34929	455	33	1
45	182468	185510	233	4520	00	3150	811	27746	237	10512	252	35459	455	33	1
46	185510	188554	233	4520	00	3554	000	29107	000	11521	000	35444	455	33	1
47	188554	191597	233	4520	00	3250	520	32187	520	15217	000	37090	455	33	1
48	191597	194641	233	4520	00	3931	711	30263	433	22344	111	39991	455	33	1
49	194641	197685	233	4520	00	6793	116	41724	788	36044	333	43686	455	33	1
50	197685	200729	233	4520	00	5692	660	41505	633	42997	333	43686	455	33	1
51	200729	203773	233	4520	00	5298	000	33481	000	27222	000	43674	455	33	1
52	203773	206817	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
53	206817	209861	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
54	209861	212905	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
55	212905	215949	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
56	215949	218993	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
57	218993	222037	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
58	222037	225081	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
59	225081	228125	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
60	228125	231169	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
61	231169	234213	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
62	234213	237257	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
63	237257	240301	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
64	240301	243345	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
65	243345	246389	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
66	246389	249433	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
67	249433	252477	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
68	252477	255521	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
69	255521	258565	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
70	258565	261609	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
71	261609	264653	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
72	264653	267697	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
73	267697	270741	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
74	270741	273785	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
75	273785	276829	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
76	276829	279873	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
77	279873	282917	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
78	282917	285961	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
79	285961	289005	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
80	289005	292049	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
81	292049	295093	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
82	295093	298137	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
83	298137	301181	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
84	301181	304225	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
85	304225	307269	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
86	307269	310313	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
87	310313	313357	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
88	313357	316401	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
89	316401	319445	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
90	319445	322489	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
91	322489	325533	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
92	325533	328577	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
93	328577	331621	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
94	331621	334665	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
95	334665	337709	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
96	337709	340753	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
97	340753	343797	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
98	343797	346841	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
99	346841	349885	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1
100	349885	352929	233	4520	00	7128	000	33771	000	21951	000	46663	455	33	1

APPENDIX I

Listing of Aggregated Engine Data

The following listing provides the values of the aggregated data cards used in the engine model. The columns are as follows:

- (1) engine code
- (2) identification code
- (3) work code
- (4) NORM
- (5) DMHR
- (6) DLB\$
- (7) DML\$
- (8) DOH\$
- (9) NIFR
- (10) NDAY
- (11) NOBS

The format of these cards is described in Appendix F.

LISTING OF AGGREGATED DATA FOR ENGINES

LISTING OF AGGREGATED DATA FOR ENGINES

83	3	1N0201	02	00	40	43	45	9	506	91	1	4047	73	3	23	03	35	09	1
83	8	2N0201	02	00	43	48	50	9	527	38	1	7898	80	4	20	86	32	80	13
84	5	2N0201	01	00	40	41	42	1	650	73	2	2000	00	7	20	01	44	80	5
85	5	2N0201	01	00	40	42	43	2	491	89	2	6027	18	0	18	32	36	45	9
86	6	2N0201	01	00	40	44	45	3	215	80	3	1175	00	2	95	27	70	96	2
86	6	2N0201	01	00	40	46	47	4	639	60	4	4764	24	0	32	37	90	50	3
86	6	2N0201	01	00	40	48	49	5	244	00	5	6075	10	0	29	48	50	29	5
86	6	2N0201	01	00	40	50	51	6	171	40	6	1722	23	3	33	62	91	23	3
86	6	2N0201	01	00	40	52	53	7	151	18	7	2850	33	2	23	32	94	29	3
86	6	2N0201	01	00	40	54	55	8	181	58	8	4096	00	0	29	07	23	28	3
89	8	2N0201	01	00	40	56	57	9	158	18	9	6881	35	0	28	86	71	00	3
89	8	2N0201	01	00	40	58	59	0	267	80	0	7299	00	0	37	09	40	83	5
89	8	2N0201	01	00	40	60	61	1	364	27	1	9441	08	9	32	25	55	74	9
89	8	2N0201	01	00	40	62	63	2	101	48	2	1476	89	5	22	33	83	59	2
89	8	2N0201	01	00	40	64	65	3	110	48	3	1743	79	5	22	33	83	59	2
89	8	2N0201	01	00	40	66	67	4	134	9	4	1893	65	3	22	33	83	59	2
89	8	2N0201	01	00	40	68	69	5	140	48	5	2211	17	5	22	33	83	59	2
89	8	2N0201	01	00	40	70	71	6	194	1	6	2062	11	7	20	87	49	80	3
91	1	2N0201	01	00	40	72	73	7	369	4	7	3335	38	2	20	90	88	19	8
91	1	2N0201	01	00	40	74	75	8	331	30	8	1865	49	9	22	88	15	47	7
92	2	2N0201	01	00	40	76	77	9	376	6	9	1328	66	0	22	88	15	47	7
92	2	2N0201	01	00	40	78	79	0	779	78	0	1523	70	3	22	88	15	47	7
92	2	2N0201	01	00	40	80	81	1	772	1	1	1337	30	0	22	88	15	47	7
92	2	2N0201	01	00	40	82	83	2	720	88	2	1105	0	0	22	88	15	47	7
92	2	2N0201	01	00	40	84	85	3	790	0	3	1362	30	0	22	88	15	47	7
92	2	2N0201	01	00	40	86	87	4	715	2	4	9423	93	7	22	88	15	47	7
92	2	2N0201	01	00	40	88	89	5	760	57	5	1232	93	7	22	88	15	47	7
92	2	2N0201	01	00	40	90	91	6	745	8	6	1239	76	6	22	88	15	47	7
92	2	2N0201	01	00	40	92	93	7	726	33	7	1875	07	2	20	51	09	50	3
92	2	2N0201	01	00	40	94	95	8	205	1	8	2193	46	5	21	18	90	23	2
92	2	2N0201	01	00	40	96	97	9	246	6	9	2856	29	2	18	90	23	2	2
92	2	2N0201	01	00	40	98	99	0	169	3	0	3705	2	9	18	90	23	2	2
92	2	2N0201	01	00	40	100	101	1	506	91	1	4047	73	3	23	03	35	09	1
92	2	2N0201	01	00	40	102	103	2	527	38	2	7898	80	4	20	86	32	80	13
92	2	2N0201	01	00	40	104	105	3	650	73	3	2000	00	7	20	01	44	80	5
92	2	2N0201	01	00	40	106	107	4	491	89	4	6027	18	0	18	32	36	45	9
92	2	2N0201	01	00	40	108	109	5	215	80	5	4764	24	0	32	37	90	50	3
92	2	2N0201	01	00	40	110	111	6	639	60	6	6075	10	0	29	48	50	29	5
92	2	2N0201	01	00	40	112	113	7	171	40	7	1722	23	3	33	62	91	23	3
92	2	2N0201	01	00	40	114	115	8	151	18	8	2850	33	2	23	32	94	29	3
92	2	2N0201	01	00	40	116	117	9	181	58	9	4096	00	0	29	07	23	28	3
92	2	2N0201	01	00	40	118	119	0	267	80	0	7299	00	0	37	09	40	83	5
92	2	2N0201	01	00	40	120	121	1	364	27	1	9441	08	9	32	25	55	74	9
92	2	2N0201	01	00	40	122	123	2	101	48	2	1476	89	5	22	33	83	59	2
92	2	2N0201	01	00	40	124	125	3	110	48	3	1743	79	5	22	33	83	59	2
92	2	2N0201	01	00	40	126	127	4	134	9	4	1893	65	3	22	33	83	59	2
92	2	2N0201	01	00	40	128	129	5	140	48	5	2211	17	5	22	33	83	59	2
92	2	2N0201	01	00	40	130	131	6	194	1	6	2062	11	7	20	87	49	80	3
92	2	2N0201	01	00	40	132	133	7	369	4	7	3335	38	2	20	90	88	19	8
92	2	2N0201	01	00	40	134	135	8	331	30	8	1865	49	9	22	88	15	47	7
92	2	2N0201	01	00	40	136	137	9	376	6	9	1328	66	0	22	88	15	47	7
92	2	2N0201	01	00	40	138	139	0	779	78	0	1523	70	3	22	88	15	47	7
92	2	2N0201	01	00	40	140	141	1	772	1	1	1337	30	0	22	88	15	47	7
92	2	2N0201	01	00	40	142	143	2	720	88	2	1105	0	0	22	88	15	47	7
92	2	2N0201	01	00	40	144	145	3	790	0	3	1362	30	0	22	88	15	47	7
92	2	2N0201	01	00	40	146	147	4	715	2	4	9423	93	7	22	88	15	47	7
92	2	2N0201	01	00	40	148	149	5	760	57	5	1232	93	7	22	88	15	47	7
92	2	2N0201	01	00	40	150	151	6	745	8	6	1239	76	6	22	88	15	47	7
92	2	2N0201	01	00	40	152	153	7	726	33	7	1875	07	2	20	51	09	50	3
92	2	2N0201	01	00	40	154	155	8	205	1	8	2193	46	5	21	18	90	23	2
92	2	2N0201	01	00	40	156	157	9	246	6	9	2856	29	2	18	90	23	2	2
92	2	2N0201	01	00	40	158	159	0	169	3	0	3705	2	9	18	90	23	2	2

APPENDIX J

Average Cost of Labor Program

- A. Purpose: This program computes the average cost of labor in dollars per man-hour for each aggregation group (i.e. the raw data cards being aggregated). A weighted average labor cost is then computed based on the number of observations in each group. This weighted average is used in the Linear Economic Model to convert man-hours into a dollar cost in the objective function.
- B. Inputs: The input data for this program is the preaggregation deck described as an input to the Aggregation Program in Appendix F.
- C. Outputs: A listing of the average cost of labor for each aggregation group followed by the weighted average cost of labor for all the groups.
- D. Special Notes: None.


```
*****  
C *****  
C CALCULATION OF THE AVERAGE COST OF LABOR PER HOUR  
C *****  
9900 REAL*8 AB  
      WRITE (6,9400)  
      FORMAT ('1,X,'AGGREGATED GROUP',5X,'LABOR',5X,'NOBS',/,  
            126X,'RATE',//)  
      NCARD=D=O  
      LL=1  
      TMHR=0.0  
      TCOST=0.0  
      C  
      READ INPUT DATA BY AGGREGATION GROUPS AND COMPUTE MEANS  
        C  
        C  
          20 READ (5,9300,END=999) N  
          9000 FORMAT (I3)  
             NCARD=NCARD+N  
             SUM=0.0  
             TOT=0.0  
             DO 1000 I=1,N  
               C  
               C  
                 9001 READ (5,9001) IB,AB,KB,DMHR,DLCB  
                   FORMAT (I2,A8,A3,22X,F6.0,F7.0)  
                   SUM=SUM+DLBC  
                   TOT=TOT+DMHR  
                   CONTINUE  
                   1000 IMHR=TMHR*TOT  
                       TCOST=TCOST*SUM  
                       DOLR=SUM/TOT  
       C  
       C  
       WRITE MEAN LABOR COST FOR EACH GROUP AGGREGATED  
  
       WRITE (6,9501)LL,IB,AB,KB,DOLRT,N  
       9501 FORMAT (' ',I6,2X,I2,A8,A3,F10.4,I8)  
           LL=LL+1  
           IF (LL.EQ.71) WRITE (6,9400)  
           GO TO 20  
     C  
     C  
     WRITE WEIGHTED AVERAGE FOR ALL GROUPS  
   C  
   C  
   DOLRT=TCOST/TMHR  
   999 WRITE (6,9502) DOLRT,NCARD  
   C  
   9502 FORMAT (' ',//,5X,'DOLLARS PER LABOR HOUR =' ,F11.5,/,  
         1 5X,'WEIGHTED AVERAGE OF THE ABOVE LABOR RATES',//,  
         2 5X,'TOTAL NO. OF OBSERVATIONS =' ,I6)  
   STOP  
   END
```


APPENDIX K

MPS/360 Data Preparation Program

- A. Purpose: This program was prepared to assist the user in preparing input data decks for use with MPS/360. The required input formats are given in Chapter 4 of Ref. 7.
- B. Inputs: A special sequence of input data cards is required. The input data cards must be in the order specified. The number of data cards in each of the below sections is not important because the program will read cards sequentially. For example, if a particular format for data requires a 10 number field with 5 columns for each number and the input data is 15 numbers then the program will read 10 numbers from the first input card and 5 numbers from the second one. All remaining columns of the second card should be blank.
- (1) The model name is punched in CC 1-8. It must be alphabetic and not begin with "X". It must be left adjusted in the field. If right hand side (RHS) parametric study vectors are required then put a "1" in CC 9. The RHS parametric vectors are "change columns" and are described in Ref. 7. They consist of a RHS column vector with zeros in every row except a "-1" in one of the resource rows. Three separate decks are created with one corresponding to each resource row. These decks

are used with MPS/360 to provide the parametric studies on the resource vector R.

(2) The number of rows in the T_1 matrix is punched in CC 1-3. The number of columns of T_1 is punched in CC 4-6.

(3) The penalty costs must be punched in this set of cards. Each card may have only 10 numbers with a 5 column field width. The computer program automatically places a decimal after the first three digits in any field. For example, if 12282 is in the 5 column field then the penalty cost is \$122.82. There should be one penalty cost for each column of T_1 .

(4) Each column of T_1 must be assigned a reference number for MPS/360. Begin with "1" and continue to number columns until all are numbered. These numbers must be punched 40 numbers per card with a 2 column field width. They must be left adjusted.

(5) Each column of T_1 produces some particular type of output. To associate each column with an output a set of cards punched with " T_1 ROW" as described in Chapter IV must be provided. Use the same format as in (4).

(6) The production vector (in man-hours) must be punched in this set of cards. The proper format is 10 numbers per card with a 5 column field width. There should be as many numbers as rows of T_1 . Use only integer values.

(7) The resource vector, R, is specified in this card. Use a 10 column field width for the three values of R1, R2 and R3 respectively. Use only integer values.

(8) The last input is the deck of aggregated data cards whose format is specified in Appendix F. They must be in the proper order to correspond with (3) and (5) above.

C. Outputs: A deck of cards is punched for use with MPS/360. However, the user must provide the MPS/360 control deck as described in Refs. 6 and 7.

D. Special Notes:

(1) Be sure not to exceed the field limits specified above.

(2) The maximum number of rows and columns for the T_1 matrix is 99 in this program. See (2) above. This also limits other inputs to a maximum of 99 input numbers. Change DIMENSION and FORMAT statements if further capacity is desired.


```
C*****
C      CALCULATION AND PUNCHING OF INPUT DATA DECK FOR MPS/360
C*****
C      DIMENSION OBJ(100), C(100), X(5,100), IB(100), JB(100), KB(100), NB(100)
C      DIMENSION M(100), L(100), RHS(100), R(3), AB(2)
C      INTEGER#2 M, L
C      REAL#8 JB
C      DATA ONE/-1.0/
C*****
C      READ INPUT DATA
C*****
C          READ (5,4,END=9999) (AB(I),I=1,2), MPARA
C          FORMAT (2A4,I1)
C          READ (5,5) P
C          FORMAT (F3.2)
C          READ (5,7) NROW, NCOL
C          FORMAT (2I3)
C          READ (5,8) (C(I), I=1,NCOL)
C          FORMAT (10F5.2)
C          READ (5,9) (M(I), I=1,NCOL)
C          FORMAT (40A2)
C          READ (5,10) (L(I), I=1,NCOL)
C          FORMAT (40A2)
C          READ (5,11) (RHS(I), I=1,NROW)
C          FORMAT (10F5.0)
C          READ (5,12) (R(I), I=1,3)
C          FORMAT (3F10.0)
C          READ (5,17)((IB(I),JB(I),KB(I),(X(J,I),J=1,5),NB(I)),I=1,NCOL)
C          FORMAT (A2,A8,A3,2F9.2,9X,2F9.2,9X,F9.2,I4)
C*****
C      WRITE INPUT DATA
C*****
C          WRITE (6,95)
C          FORMAT ('1,6X,' IDENTIFICATION',8X,'NORM',11X,'DMHR',11X,'DML$','
C          111X,'DOH$','11X,'NDAYS',7X,'NOBS',//)
C          DO 100 I=1,NCOL
C            IF (I.EQ.71) WRITE (6,95)
C            WRITE (6,97) I, IB(I), JB(I), KB(I), {X(J,I), J=1,5}, NB(I)
C            FORMAT (' ',14,2X,A2,A8,A3,5F15.3,I8)
C          CONTINUE
C*****
C      NORMALIZE ACTIVITY VECTORS
C*****
C          DO 200 I=1,NCOL
C          C
C          C
C          C
```



```

Z=X(1,1)
DO 150 J=1,5
X(J,1)=X(J,1)/Z
CONTINUE
C
C
C CALCULATE AND PRINT ALL LP VALUES

WRITE (6,250) (AB(I),I=1,2)
FORMAT (1,15X,MODEL NAME = ,2A4,/)
WRITE (6,260)
FORMAT (1,10X,70HCOL NO. ROW NO. OBJ ROW E ROW R1 ROW
1 R2 ROW R3 ROW ,/)
DO 300 I=1,NCOL
IF (I.EQ.71) WRITE (6,1001)
FORMAT (1,10X,70HCOL NO. ROW NO. OBJ ROW E ROW R1 ROW
1 R2 ROW R3 ROW ,/)
OBJ(I)=P*X(2,1)+X(3,1)+X(4,1)+C(I)*X(5,1)
WRITE (6,301) L(1),M(1),OBJ(I),ONE,{X(J,1),J=2,4}
FORMAT (1,11X,A2,8X,A2,3X,5F10.4)
CONTINUE
WRITE (6,305)
FORMAT (1,15X,'RIGHT HAND SIDE VALUES',/,/,15X,'ROW NO.',
19X,'RHS VALUE',/)
WRITE (6,306) (L(I),RHS(I)),I=1,NROW)
FORMAT (6,306) (L(I),RHS(I),I=1,NROW)
WRITE (6,307) L(1),M(1),OBJ(I),ONE,{X(J,1),J=2,4}
FORMAT (6,307) L(1),M(1),OBJ(I),ONE,{X(J,1),J=2,4}
CONTINUE
PUNCH INPUT DECK FOR MPS/360
C
C
WRITE (7,310)
FORMAT (7,310) (MPS2,SYSIN DD ,*)
WRITE (7,320) (AB(I),I=1,2)
FORMAT (7,320) (AB(I),I=1,2)
WRITE (7,350)
FORMAT (7,350) (ROWS,/,1X,'N',2X,'OBJ',)
DO 400 I=1,NROW
WRITE (7,401) L(I)
FORMAT (7,401) L(I)
CONTINUE
DO 500 I=1,3
WRITE (7,501) I
FORMAT (7,501) I
CONTINUE
WRITE (7,550)
FORMAT (7,550) (COLUMNS)
DO 600 I=1,NCOL
WRITE (7,601) L(I),OBJ(I)

```



```

601  FORMAT (4X,'Z',A2,7X,'OBJ',7X,F12.4)
602  WRITE (7,602) L(I),M(I),ONE,X(2,I)
603  FORMAT (4X,'Z',A2,7X,'E',A2,7X,F12.4,3X,'R1',8X,F12.4)
604  WRITE (7,603) L(I),X(3,I),X(4,I)
605  FORMAT (4X,'Z',A2,7X,'R2',A2,7X,F12.4,3X,'R3',8X,F12.4)
606  CONTINUE
750  WRITE (7,750)
    FORMAT ('RHS')
    DO 800 I=1,NROW
    RHS(I)=-RHS(I)
    WRITE (7,801) L(I),RHS(I)
    FORMAT (4X,'RHS',7X,'E',A2,7X,F12.4)
    CONTINUE
801  DO 900 I=1,3
802  WRITE (7,901) I,R(I)
    FORMAT (4X,'RHS',7X,'R',I1,8X,F12.4)
    CONTINUE
900  IF (MPARA.EQ.0) GO TO 945
    DO 910 J=1,3
    DO 920 I=1,NROW
    WRITE (7,921) J,L(I)
    FORMAT (4X,'RHS',I1,6X,'E',A2,13X,'0.0')
    CONTINUE
921  DO 930 K=1,3
922  IF (J.EQ.K) GO TO 940
    WRITE (7,931) J,K
    FORMAT (4X,'RHS',I1,6X,'R',I1,14X,'0.0')
    GO TO 930
940  WRITE (7,941) J,K
941  FORMAT (4X,'RHS',I1,6X,'R',I1,13X,'-1.0')
942  CONTINUE
943  CONTINUE
944  WRITE (7,950)
945  FORMAT ('ENDATA')
    GO TO 2
999  WRITE (6,1000)
1000  FORMAT ('!')
    STOP
    END

```


APPENDIX L

Cluster Centroid Dominance Program

- A. Purpose: This program takes an input deck of aggregated data cards (processes) and a set (more than one if desired) of cluster descriptions and produces a dominance matrix showing the relationships between cluster centroids (or "aggregated" processes).
- B. Inputs: A control card with the number of aggregated data cards punched in CC 1-3 is first. Aggregated data cards then follow this card. Next the user may put several cluster "descriptions" if desired. (At least one is required.) The cluster "description" format is specified in Appendix E.
- C. Outputs: A cluster description, centroid data listing and dominance matrix are provided for each cluster description. A list of efficient groups is listed. An efficient group is a centroid that is not dominated by any other centroid.
- D. Special Notes:
- (1) The dominance matrix shows an "O" where each centroid is either dominates or is dominated. The number of "O's" in each row and column are listed at the sides of the matrix. A "-" means no dominance relationship exists.

(2) The maximum number of centroids in any cluster description is 50.

(3) The maximum number of aggregated data cards is 100.


```

*****
CHECK CLUSTER CENTROIDS FOR DOMINANCE
THIS PROGRAM WILL TAKE MULTIPLE CLUSTER
DESCRIPTIONS FOR ANALYSIS
*****
DIMENSION X(6,100),MCLUS(100),LOCN(101),NAME(100),NUMB(100)
1 CENTR(6,50);D(5);TOT(50,50);IEFF(50);ITOT(50);JTOT(50);Y(6)
DATA IDASH/'-'/,'IOH','O/','ISTR','*'/
DATA Y/'NORM','DMHR','DML$','DOH$','NDAY','NOBS.'/
ISW=0
READ(5,7) N
FORMAT{13}
READ INPUT DATA
17 READ(5,17){X(J,I),J=1,6},I=1,N)
   FORMAT {13X,2F9.2,9X,2F9.2,9X,F9.2,F4.0}
READ CLUSTER DESCRIPTIONS
20 READ (5,7,END=9999) NCLUS
   READ(5,37){NUMB(I),I=1,NCLUS)
   FORMAT{20I3,20X}
37 READ(5,37){MCLUS(I),I=1,N)
   LOCN(I)=1,NCLUS
   DO 50 K=1,NCLUS
     ITOT(K)=0
     JTOT(K)=0
     LOCN(K+1)=LOCN(K)+NUMB(K)
     NAME(K)=MCLUS(LOCN(K))
     DO 50 KK=1,NCLUS
       IOUT(K,KK)=IDASH
     CONTINUE
50   DO 60 K=1,NCLUS
60   IOUT(K,K)=ISTR
     NEFF=0
WRITE INPUT DATA
IF(ISW.EQ.1) GO TO 70
WRITE(6,62) Y
FORMAT {1I,1X,5A15,A13,/}
62 DO 99 I=1,N
   WRITE (6,97) I,(X(J,I),J=1,6)

```



```

97 FORMAT (' ', I4, 5F15.5, F8.0)
99 IF (I.EQ.70) WRITE (6,62) Y
C CONTINUE
C WRITE CLUSTER
70 WRITE (6,65)
65 FORMAT ('1', //)
287 WRITE(6,287) NCLUS
    FORMAT('OSTAGE', I4)
    DO 290 I=1,NCLUS
        L=LOCN(I)
        LL=LOCN(I+1)-1
290 WRITE(6,297) I, NAME(I), (MCLUS(K), K=L, LL)
297 FORMAT(15, ' GROUP', I4, I10, I9I4, /, (16X, 20I4))
C COMPUTE WEIGHTED GROUP CENTROIDS
    DO 100 K=1,NCLUS
    DO 100 J=1,5
        CENTR(J,K)=0.0
    DO 150 K=1,NCLUS
        ZNK=0.0
        NK=NUMB(K)
        L=LOCN(K)-1
    DO 140 I=1,NK
        MG=MCLUS(L+1)
        ZNK=ZNK+X(6,MC)
    DO 140 J=1,5
        CENTR(J,K)=CENTR(J,K)+X(J,MC)*X(6,MC)
    DO 145 J=1,5
        CENTR(J,K)=CENTR(J,K)/ZNK
140 CENTR(6,K)=ZNK
145 CONTINUE
150 C WRITE WEIGHTED GROUP CENTROIDS
    C IF (NCLUS.GT.30) WRITE (6,65)
    WRITE(6,147) Y
147 FORMAT('1', //, 21X, 5A15, A13, /)
155 WRITE(6,155) (K, NAME(K), (CENTR(J,K), J=1,6), K=1,NCLUS)
    C FORMAT(15, ' GROUP', I4, ' CENTROID', 5F15.5, F8.0)
    C NORMALIZE CENTROIDS TO UNIT OUTPUT
    DO 200 K=1,NCLUS
        Z=CENTR(1,K)
    DO 200 J=1,5

```



```

200  CENTR(J,K)=CENTR(J,K)/Z
C
C  WRITE NORMALIZED CENTROIDS
C
148  WRITE (6,148) (Y(I),I=1,5)
      FORMAT ('1',/,/,23X,5A10,/)
157  WRITE (6,157)(K,NAME(K), (CENTR(J,K),J=1,5),K=1,NCLUS)
C      FORMAT(15,' GROUP',14,' CENTROID',5F10.3)
C
C  CHECK FOR DOMINANCE AND STORE RELATIONSHIPS
C
      NCLUS=NCLUS-1
      DO 400 K=1,NCLUS
        KPI=K+1
        DO 400 KK=KPI,NCLUS
          DO 250 J=2,5
            D(I)=CENTR(J,K)-CENTR(J,KK)
            IF (D(2).GE.0).AND.(D(3).GE.0).AND.(D(4).GE.0).AND.(D(5).GE.0)
              1 GO TO 300
              1 IF (D(2).LE.0).AND.(D(3).LE.0).AND.(D(4).LE.0).AND.(D(5).LE.0)
                GO TO 350
                GO TO 400
                IOUT(K,KK)=IOH
                ITOT(K)=ITOT(K)+1
                JTOT(KK)=JTOT(KK)+1
                GO TO 400
          IOUT(KK,K)=IOH
          ITOT(KK)=ITOT(KK)+1
          JTOT(K)=JTOT(K)+1
        CONTINUE
      400 CONTINUE
C
C  WRITE DOMINANCE MATRIX
C  ( IF NUMBER OF CLUSTERS IS 30 OR LESS )
C
      IF (NCLUS.GT.30) GO TO 600
      WRITE (6,149)
      FORMAT ('1',/,/)
149  WRITE (6,502) (I,I=1,NCLUS)
502  FORMAT ('5X',GROUP',5X',DOM BY',3X,5013)
      WRITE (6,398)
      FORMAT ('1',/)
398  DO 500 I=1,NCLUS
      WRITE (6,501) I,ITOT(I),IOUT(I,J),J=1,NCLUS
501  FORMAT ('1',,7X,13,6X,14,6X,50A3)
      IF (ITOT(I).NE.0) GO TO 500
      IEFF=NEFF+1
      NEFF=NEFF+1
      CONTINUE
500

```



```

554      WRITE (6,398) (JTOT(I), I=1,NCLUS)
C      WRITE (6,554)
C      FORMAT (' ',24X,50I3)
C      WRITE THE EFFICIENT GROUPS
C
555      WRITE (6,149)
C      WRITE (6,555) (IEFF(I), I=1,NEFF)
C      FORMAT (' ',10X, 'THE EFFICIENT GROUPS ARE' ,25I3)
C      ISW=1
C      GO TO 20
C
C      WRITE DOMINANCE MATRIX
C      ( IF NUMBER OF CLUSTERS IS GREATER THAN 30 )
C
600      WRITE (6,65)
C      WRITE (6,602) (I, I=1,NCLUS)
602      FORMAT (' ',5X, 'GROUP',5X, 'DOM BY',4X,50I2)
C      WRITE (6,398)
C      DO 700 I=1,NCLUS
C      WRITE (6,601) I, ITOT(I), (IOUT(I,J), J=1,NCLUS)
601      FORMAT (' ',7X,13,6X,14,6X,50A2)
C      IF (ITOT(I).NE.0) GO TO 700
C      IEFF(NEFF+1)=I
C      NEFF=NEFF+1
C      CONTINUE
700      WRITE (6,398)
C      WRITE (6,654) (JTOT(I), I=1,NCLUS)
654      FORMAT (' ',25X,50I2)
C      WRITE (6,149)
C      WRITE (6,555) (IEFF(I), I=1,NEFF)
C      ISW=1
C      GO TO 20
9999      STOP
C      END

```


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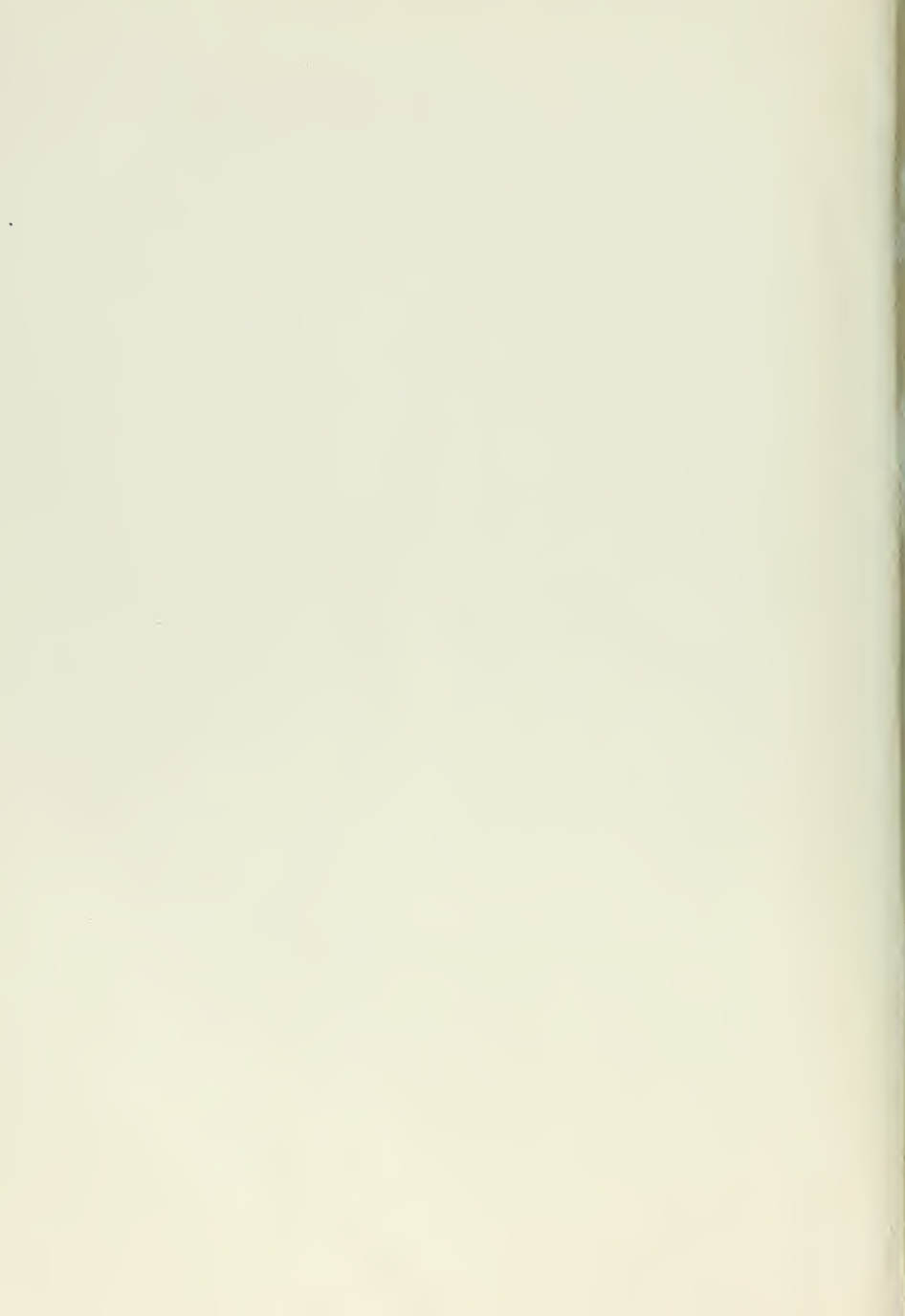
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13. ABSTRACT

A prototype management information system called Work-in-Process Inventory Control System (WIPICS) has been installed at the Naval Air Rework Facility (NARF), North Island. WIPICS is expected to benefit the NARF by reducing rework times and rework costs. By assuming that linear production processes may be estimated from statistical data accumulated by the NARF, a linear economic model is constructed which predicts a required budget in man-hours, material cost and overhead cost categories for a specified production output level. Sample problems are solved and parametric studies are done to determine changes in the required budget for restrictions in man-hours, material cost and overhead cost. The model will be used as an aid in the cost-effectiveness evaluation of WIPICS by the Management Systems Development Office.



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